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Collaborative Geographic Visualization

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SUMÁRIO

Este documento é uma revisão de alguma da literatura essencial, enquanto corpo de conhecimento básico, ao desenvolvimento eficaz do uso de tecnologias de computação ubíqua na visualização colaborativa de Sistemas de Informação Geográfica (SIGs).

Os capítulos que o compõe tomam por foco, respectivamente, os SIGs nas suas componentes gerais, multimédia e ubíquas; a visualização de informação geo-referenciada e as suas componentes gráficas de realidade virtual e aumentada; os ambientes colaborativos com os seus requisitos tecnológicos, as suas especificidades arquitecturais, e os seus modelos de gestão colectiva de informação; e, por fim, algumas considerações sobre o futuro e os desafios da visualização colaborativa de SIGs em ambientes ubíquos.

ABSTRACT

The present document is a revision of essential references to take into account when developing ubiquitous Geographical Information Systems (GIS) with collaborative visualization purposes.

Its chapters focus, respectively, on general principles of GIS, its multimedia components and ubiquitous practices; geo-referenced information visualization and its graphical components of virtual and augmented reality; collaborative environments, its technological requirements, architectural specificities, and models for collective information management; and some final considerations about the future and challenges of collaborative visualization of GIS in ubiquitous environments.

Contents

List of Abbreviations

AMC	Adaptive Modulation and Coding
AR	Augmented Reality
ATM	Asynchronous Transfer Mode
CAD	Computer-aided Design
CAM	Computer-aided Manufacturing
CSCW	Computer Supported Collaborative Work
EDGE	Enhanced Data Rates for GSM Evolution
ESRI	Environmental Systems Research Group
DEM	Digital Elevation Model
DPS	Digital Product Simulation
GIS	Geographic Information System
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
GUI	Graphical User Interface
HARQ	Hybrid Automatic Request
HCI	Human-Computer Interface
HMD	Head-mounted Displays
HSCSD	High-Speed Circuit Switch Data
HSDPA	High-Speed Downlink Packet Access
HSUPA	High-Speed Uplink Packet Access
HUD	Head-Up Displays
IBM	Business Machines Corporation
IRC	Internet Relay Chat
LAN	Local Area Network
LBS	Location Based Services
MIMO	Multiple-input Multiple-output Communications
MIT	Massachusetts Institute of Technology
MPEG	Motion Pictures Experts Group
OGS	Open GIS Consortium
PDA	Personal Digital Assistant
PSK	Phase-shift Keying
TIN	Triangular Irregular Network
TUI	Tangible User Interfaces
SNIG	Portuguese National System for Geographic Information

SQL	Structured Query Language
SVG	Scalable Vector Graphics
UMTS	Universal Mobile Telephone System
URL	Uniform Resource Locators
VE	Virtual Environment
VR	Virtual Reality
WAP	Wireless Application Protocol
WLL	Wireless Local Loops
WWW	World Wide Web
XML	Extensible Mark-up Language

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Introduction

1.1 The Purpose of this Document

Collaborative geovisualization is an important challenge in the development of Geographical Information Systems (GIS), since most work with geospatial information requires coordinated effort by groups. This document has as its main goal to review literature that can provide, for different reasons, essential and basic information for the present development of collaborative visualization with ubiquitous GIS. This review surveys work that has been made in the different arenas of GIS, geovisualization and collaboration, and provides an overview of what has already been accomplished either by drawing on the writings of its authors, either by presenting their results as examples.

The aim of this document goes towards the use of Computer Supported Collaborative Work (CSCW) in geographical information science, to which relevant references are the reviews made by MacEachren (2000, 2001), the book by Jankowski and Nyerges (2001) and the paper by Maybury (2001).

1.2 Overview of the Document

In addition to this introductory chapter, this document has five chapters, outlined as follows:

Chapter 2: Geographical Information Systems This opening section revues basic concepts and representations of GIS. It surveys the uses of different types of data in multimedia applications and the use of the World Wide Web as the most widely used platform for the integration and distribution of several layers of media in GIS. It also resumes ubiquitous computation technologies for the development of distributed, mobile, and context-aware GIS.

Chapter 3: Visualization This chapter draws on the visualization of geo-referenced data through the discussion of principles of information visualization, and the several types of data and tasks normally used and performed. It surveys virtual and augmented reality technologies as core tools for geographical information.

Chapter 4: Collaborative Environments It focuses on the requirements, possibilities and strategies of collaborative visualization environments. It surveys tools for synchronous and asynchronous collaborative visualization, basic principles for the design of collaborative environments, and models for collaborative information visualization.

Chapter 5: Conclusions This last chapter resumes important information gathered along the previous ones, discusses some present challenges for collaborative visualization of ubiquitous GIS, and draws on possibilities for future work on this subject.

2

Geographical Information Systems

2.1 Introduction

Geographic Information Systems (GIS) refer to information systems and the several fields of knowledge that use spatial analysis techniques (Schee, 1995). These systems have the principle functions of capturing, storing, representing, manipulating, analysing, modelling and displaying geo-referenced data in two and three dimensions worlds (Laurini and Thompson, 1992). The development and application of a GIS includes (Jones, 1997):

- *Data acquisition:* obtaining digitised spatial and alphanumerical information;
- *Preliminary data processing:* interpreting, classifying and structuring digital data;
- *Database construction:* modelling, structuring, updating and loading the database;
- *Retrieval:* retrieve data by location, class or attribute;
- *Analysis:* searching for patterns, associations, routes, and interactions; modelling and simulation of spatial phenomena;
- *Visualization:* creating maps and exploring data.

GIS applications are widely used for environmental purposes in urban and regional planning, natural resource management, environmental impact assessment, routing and location problems, and emergency and maintenance plans.

Maps, the most common visualization tool of GIS, are topographic or thematic symbolic representations of the terrain, using overrepresentation, simplification and symbolism of features (Camara, 2002).

Terrains are a set of spatial entities, such as point and line objects, areas, surfaces and volumes (Jones, 1997). Terrains may be characterised by unitary properties such as length, surface area, volume, shape, orientation and slope. Or by instance properties such as patterns, layouts, distances, enclosures, connections, flows, and land use (Laurini and Thompson, 1992).

Digital Elevation Models (DEMs) (Figure 2.1) are common terrain representations in GIS modelling and visualization. Moore *et al.* (1991) and Mitasova *et al.* (1995) have used DEMs in the modelling of hydrological phenomena, and Gonçalves and Diogo (1994) in the modelling of forest fires. Because in DEMs only some points have precise elevations, while the remaining are interpolated, methods of local neighbourhood, such as Delaunay's triangulation, or methods relying on kriging or splines, are used to minimise the errors associated with the interpolation process (Mitas and Mitasova, 1999). Triangulation procedures build topography by developing Triangular Irregular Networks (TIN's) (Figure 2.2), estimating values at unsampled locations through the existing data points (Jones, 1997). Splines are functions that pass through the data points as smooth as possible, while kriging methods are not adequate when local geometry and smoothness are key issues (Mitas and Mitasova, 1999).

Moreover, GIS can be developed and applied using both vector and raster models.

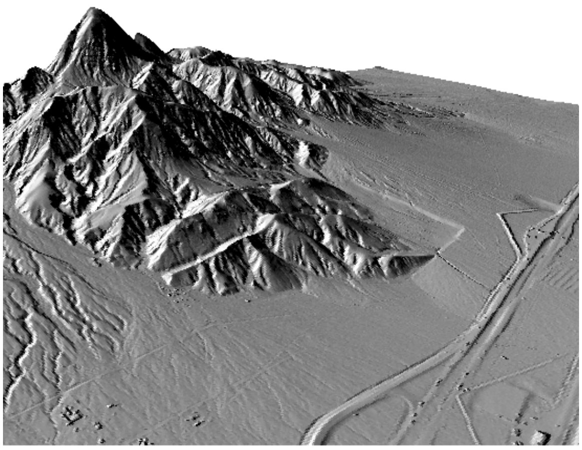

Figure 2.1 Digital Elevation Model.

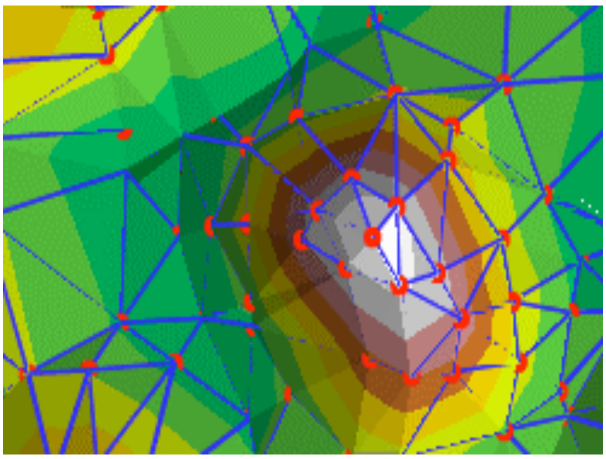

Figure 2.2 Triangular Irregular Network.

Source: http://webhelp.esri.com.

Vector models (Figure 2.3) enable the recognition of topological relationships by representing phenomena using geometric primitives (points, lines, areas, surfaces, and volumes), to which non-spatial attributes, such as social and environmental variables, are associated (Jones, 1997). Topology is preserved either through developing relational databases that use tables to enable queries based on the relationships of connectivity and adjacency, either by the use of network analysis tools (Zhan, 1998). Vector models have been used for environmental purposes in studies such as solid waste collection routing (Bodin et al., 1989 and Chang et al., 1997), location of regional waste water treatment systems (DeMelo and Camara, 1994), and sewer design implementation (Greene et al., 1999).

A raster model (Figure 2.4) divides space into cells of a grid, so that it can be mapped on to a Euclidean geo-referenced matrix. Satellite imagery and aerial photographs are representative examples of this model. In GIS each cell of the matrix assumes a numerical value, obtained through sampling or interpolation, corresponding to specific thematic information. Raster models are used on overlay analysis in land use suitability studies, with remote sensing images, for minimising the environmental impacts of siting power plants, waste water treatment plants, solid waste treatment plants, landfills, highways, pipelines, and power lines (Church, 1999).

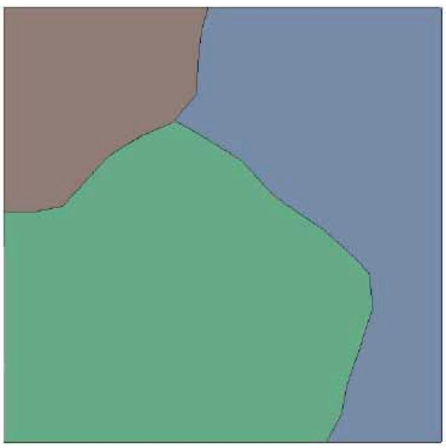

Figure 2.3 Vector Model.

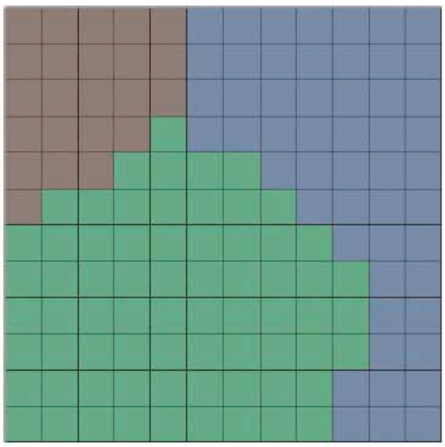

Figure 2.4 Raster Model.

Source: www.urbanecology.washington.edu.

Spatial data structures have been developed for raster maps or images to facilitate storage and retrieval of geographical representations of the same site at different resolutions (Samet, 1989a, b). Camara (2002) identifies two major data structures used in GIS: the tree and the R-tree. The latter handles with rectangular regions of an image or map, while the former is useful for storing information by levels.

2.2 Multimedia Geographical Information Systems

The multimedia concept refers to the simultaneous integration of distinct media types in one computer-based application (Lipton, 1992; Raper, 1995). A multimedia GIS may be characterized as a computer based system consisting of hardware, software, data and applications allowing integrated digital capture and editing, storing and organization, modelling and analysis, presenting and visualizing spatially referenced data of multiple time-dependent and time independent media (Steinmetz *et al.,* 1990).

Multimedia capabilities can be explored to facilitate access to environmental information, to improve the explanation of environmental phenomena and to heighten the perception of environmental processes. The incorporation and manipulation of videos, images and sounds with spatial data facilitates the perception of environmental time and space, allowing users' access to multiple views of the same reality and increasing the available data for environmental analysis (Fonseca *et al*., 1999). The integration of multimedia in a users environment means that the user is not only viewing multimedia information but also creating and authoring multimedia objects (Bill, 1999), while controlling access and manipulating an enormous amount of data (Ambron and Hooper, 1988).

Interactive multimedia systems for environmental applications have been developed in fields such as interactive water resources modelling systems (Locus *et al*., 1985), decision support systems for estuarine water-quality management (Arnold and Orlob, 1989), interactive environmental software (Fedra, 1993) and hypermedia systems to explore watershed information (Camara, 1989).

2.2.1 Image Data

Image data refers to collections of objects defined by the shape of the region within which they are located, and by the properties of the pixels in the given image (Camara, 2002).

Images that are usually used in GIS for environmental studies are:

- Remote Sensing Imagery, for issues such as land use, desertification, protected areas, erosion, landslides, flooding, forest fires, and renewable energy (Bauer, 1991 and Foody and Curran, 1994).
- *Aerial Photography*, for environmental impact assessment and coastal management (Cohen *et al.*, 1995 and Knott *et al.*, 1997).
- *Digital Terrain Models* are used in environmental modelling *and* visualization projects (Moore *et al.*, 1991, Mitasova *et al., 1995,* and Gonçalves and Diogo, 1994).
- *Ground Photography*, for urban planning (Owens, 1993) and landscape analysis (Kent and Eliot, 1995).

Database models, in which images can be stored through procedures of compression and segmentation, include the relational model, the spatial data structure model, and the object-oriented model. Examples of large databases of image data that can be used in environmental management are the Microsoft Terra Server, the Massachusetts Institute of Technology's (MIT) orthophoto collection, and the Portuguese National System for Geographic Information's (SNIG) collection of aerial photos.

2.2.2 Video Data

Video is a sequence of images called frames. Important features of video are the frame rate and the number of scanning lines or rows of pixels. The most common video standards are the NTSC format (30 frames per second and 525 scanning lines) and the PAL format (25 frames per second and 625 scanning lines). Popular Internet video formats are QuickTime, the Motion Pictures Experts Group format (MPEG), Real Video, Windows Media, Xvid, DivX, H264, iPod and Flash Video.

Like with image, video data storage also requires the use of compression and segmentation procedures. The main goal of video database query is to find segments that satisfy given conditions, objects, activities, properties, and videos or video segments in which objects/activities with certain properties occur (Subramanian, 1998). A system that was developed to retrieve image and video data on the internet using textual descriptions as well as visual information is Webseek (Chang *et al*., 1997). Later on, several search engines, such as Google Videos (Figure 2.5), included video query, mostly based on textual descriptions. Nobre (1999) also has developed a spatial indexing system for video.

A wide range of applications that use video technology for monitoring purposes can be found: monitoring of industrial emissions (Weibring *et al.,* 1998); a system to estimate parameters for air pollution models (Ferreira, 1998); assessment of pipeline environmental impacts (Um and Wright, 1996); coastal management (Raper and McCarthy, 1994); pedestrian traffic analysis (Rourke and Bell, 1992); vehicle counting and identification of vehicle type (Michalapoulos and Wolf, 1990; Kilger, 1992); vehicle emissions measurements using infrared cameras (Lawson *et al.*, 1990; Stephens and Cadle, 1991; Zhang *et al.*, 1993); the detection of chemical clouds either by infrared (Althouse and Chang, 1991), or by ultraviolet for sulphur dioxide (McElhoe and Conner, 1986).

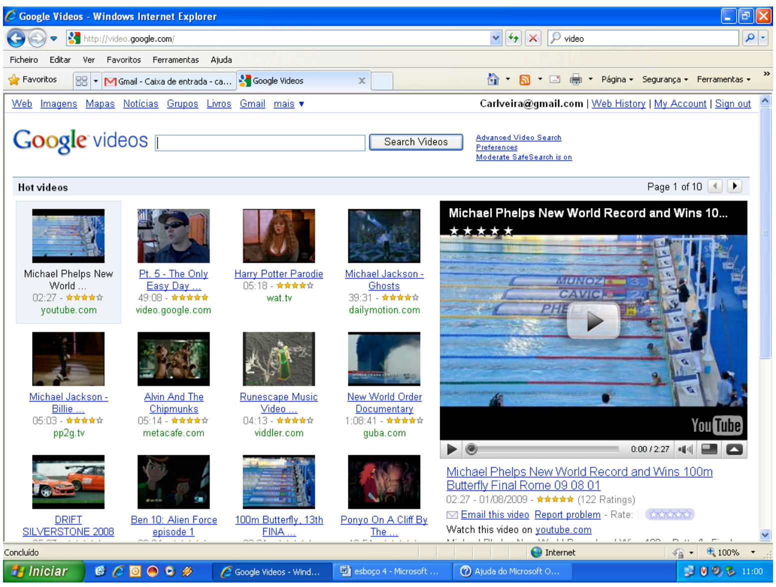

Figure 2.5 Google Videos.
Source: http://video.google.com/.

2.2.3 Audio Data

Environmental digital systems use sound to reproduce environmental features and to improve their user interface (Camara, 2002). Sound is the superimposition of sine waves with different frequencies and amplitudes (Lockus *et al*., 1973). Sound frequency refers to how quickly the air vibrates and it is felt as the pitch of a sound. Sound amplitude refers to the amount of pressure exerted by the air and it is felt as the loudness of a sound (Scaletti and Craig, 1993). From an environmental standpoint, other features of sound are its location, its length, its timbre, the relation of sound with silence, the sequence of sounds over time, and the time it takes a sound to reach its maximum or minimum intensity level (Krygier, 1994).

Audio databases rely on metadata indexing schemes. Audio databases may be indexed using audio signal processing procedures such as segmentation, splitting up the audio signal into relatively homogeneous windows, and feature (intensity, loudness, pitch, and brightness) extraction (Subramanian, 1998).

Sound can also be used in environmental decision support systems to represent abstract data, convey system status information, and warn the user (Buxton, 1989).

Noise has been extensively studied in the context of residential areas (Fileds, 1998), impacts of railways (Kurze, 1996), and airport and aircraft noise (Attenborough, 1998; Zaporozhets and Tokarev, 1998; Scholten 1998).

2.2.4 Text Data

Text is the most widely used media form in multimedia systems (Tannenbaum, 1998). Representation of segments of text as vectors, through comparisons between vectors reflecting text similarity, enable the automatic development of links within text and, thus, hypertext. Metadata for text objects includes content description, storage information, and historical status information (Witten *et al*., 1994). These methods allow automatic analysis and search, theme generation, and summarisation of text (Salton *et al*., 1994). Commercial databases providing text retrieval include Informix, Oracle, and International Business Machines Corporation's (IBM) DB2.

2.3 Geographical Information Systems and the WWW

The World Wide Web (WWW) is the most developed platform for the integration of different technologies into several layers of media. This type of hypermedia interface has become the standard for the distribution of geographical information (Bodum, 1995; Mitchell, 1995; Schiffer, 1995; Batty, 1997; Raper, 1997).

Hypermedia geographic information systems, being based on a structure of nodes and links, allow the user to, freely and intuitively, explore a set of data (Fonseca *et al.*, 1999).

When a hypermedia spatial database is integrated with coordinate-based spatial referencing such that each spatial "object" has a stored location, the system can be defined as hypermap. It is a clickable map, from which the user can access different layers information, such as text, tables, images, or other maps (Raper, 1997). The layers are connected to each other by hyperlinks. Each layer is also linked to the information's database. The data obtained when clicking on a hypermap is related to the clicked position. This hypermedia structure allows the user to access the same information via different paths (Romão *et al.*, 1999).

Hypermedia systems design is driven by technological innovations and user-oriented issues, associated with cognition and human information processing (Thuring *et al.,* 1995). Two major approaches in the design of hypermedia systems in regard to cognitive aspects are the explorer approach, in which the user gathers knowledge while navigating through large sets of information, and the document centred approach, in which the user is guided through the information along a pre-defined structure (Stotts and Furuta, 1991).

The hypermedia system's degree of coherence affects the users' ability to understand and remember a subject. At the local level the fragmentation of hypertext should be limited, to avoid a lack of interpretative context; at the global level, cues must able the user to identify the major components of the application and its overall structure (Fonseca *et al.*, 1999).

Necessary cues for orientation, navigation and user-interface adjustment must be considered in order to reduce the effort and concentration necessary to maintain several tracks at one time (Conklin, 1985). Orientation cues able the user to identify the current position within the overall structure, reconstruct the route that led to that position and distinguish among different options for moving on from this position (Thuring *et al.*, 1995). Navigation cues able the user to distinguish forward and backward directions, and the distance of nodes. User-interface adjustments are also important in order to eliminate dispensable activities in the use of the system (Fonseca *et al*, 1999). The design of the interface for hypermedia GIS should take into consideration the functional requirements of the system according to the tasks to be performed, the model's adaptation to the users' cognitive representations, and the definition of the types of dialog with the user. Multimedia models also have to be developed in order to support a high degree of interactivity (Laurel, 1990).

Figure 2.6 Google Earth.

Source: http://earth.google.com.

Hypermedia GIS can be published and explored either through static maps that, because of supporting vector formats, enable unlimited magnification and organisation of the information in different layers for selective visualization, or through interactive maps using servers that dynamically publish maps responding to users' requests (Camara, 2002).

The shift towards service-oriented models for GIS, using the Internet as infrastructure of deliverance to users, resulted not only in the rise of the number of products, but also in the increasing of the interoperability between heterogeneous geographical data types and between geographical and non-geographical data types (Alameh, 1998).

Some spatial databases that became Web-enabled by using a client-server model are Intergraph's Geomedia, Autodesk's MapGuide, the Environmental Systems Research Group's (ESRI) Internet Map Server, MapInfo Map X, GRASSlinks, Google Earth (Figure 2.6) and Google Maps. Simultaneous querying of several Web based GIS is possible through Java based applications (Wang and Jusoh, 1999) and Scalable Vector Graphics (SVG), a language for describing two dimensional vector, image, and text graphics in Extensible Mark-up Language (XML) (Gould and Ribalaygua, 1999).

2.4 Ubiquitous Geographical Information Systems

Pervasive or ubiquitous computing and ambient intelligence are terms usually used to refer to environments that recognize and respond to the presence of individuals through invisible and unobtrusive computers functioning in the background (Weiser, 1991; Ahola, 2001; Bohn et *al*., 2004; Leem *et al*., 2007). Pervasive computing delivers mobile access to business information without limits, from any device, over any network, using any style of interaction. Through this implantation, the physical world gains digital qualities, such as computer addressability through unique identification codes (Borcea *et al.*, 2004). Ubiquitous environments require small, inexpensive, and low-powered computers with convenient displays such as Personal Digital Assistants (PDA's), Handheld Personal Computers and wearable computers. They also require robust and efficient networks, being the Internet the logical backbone between ubiquitous computers, and software systems that support ubiquitous applications (Hunter, 2000). Ubiquity, in the sense of personalized GIS adapted to the current context, is a natural development for GIS. For a GIS to be ubiquitous, its architecture must be open and device independent, allowing information to be presented and communicated with people in all computing environments (Herring, 2007). Ubiquitous GIS must also be (Goodchild *et al.,* 1997):

- *Distributed*, that is data storage, processing and user interaction can occur at locations that are potentially widely scattered;
- *Disaggregated*, that is the monolithic systems are replaced by components with instant connectivity that are designed to interoperate through conformance with industry-wide standards;
- *Decoupled*, that is the system must be able to access a number of components that may be required to complete a specific task, which may be distributed over many networks;
- *Interoperable*, which means the system is based on an open system such as that promulgated by the Open GIS Consortium (OGS).

2.4.1 Wireless Technologies

The wireless component is considered to be the enabling element of a mobile GIS. Wireless data access allows users to be more productive by allowing them to get and disseminate the information they need wherever they are.

Wireless networks work by superimposing data on radio carriers. By utilizing different frequencies multiple users can coexist in the same radio space. Wireless services are designed around either packet switching or circuit switching. With packet switching messages are divided into packets before they are sent. Each packet is then transmitted individually and can even follow different routes to its destination. Once all the packets forming a message arrive at the destination, they are recompiled into the original message. Packet switching is more efficient and robust for data that can withstand some delays in transmission, such as e-mail messages and Web pages. On the other hand, with circuit switching, a dedicated line is allocated for transmission between two parties, being ideal when data must be transmitted quickly and must arrive in the same order in which is sent. It is the case with most real time data, such as live audio and video (Hunter, 2000).

Danado (2008) surveys the existing different wireless technologies as follows:

- *Bodynet.* Data can be sent by creating an external electrical field that passes an incredibly tiny current through the body (Zimmerman, 1996).
- *Local Area Network (LAN)*. The IEEE's 802.11 standard and the HIPERLAN are designed to cover small areas. The IEEE 802.11 family of protocols is applied to wireless Asynchronous Transfer Mode (ATM) systems.
- *Wireless Local Loops (WLL)*. Fixed wireless access points that are suitable for use as highspeed Internet access.
- *Satellites.* The satellite moves through the users' cell rather than the user moving through a cell relating to a particular access point on the ground.
- *Zigbee.* Built around the IEEE 802.15.4 wireless protocol, it is designed for highly efficient connectivity between small devices that can be sustained with a small battery for a long time.
- *Bluetooth*. Operates in a license-free frequency, uses frequency hopping spread spectrum to minimize interference problems, has low energy consumption, has worldwide availability, and has low-price.
- *General Packet Radio Service (GPRS).* Only subject to radio coverage, eases connections whereby information can be sent or received immediately.
- *High-Speed Circuit Switch Data (HSCSD).* It is a high-speed, multi-slot data communication platform for Global System for Mobile Communications (GSM) networks.
- *Enhanced Data rates for GSM Evolution (EDGE).* It is a method to increase data rates over GSM radio links that, through Phase-shift Keying (PSK) modulation and channel coding, transmits both packet-switched and circuit-switched voice and data services.
- *Universal Mobile Telephone System (UMTS).* It is an infrastructure that supplies facilities, appropriate bandwidth and quality for end-users and their applications.
- *High-Speed Downlink Packet Access (HSDPA).* It is a mobile telephony protocol that includes Adaptive Modulation and Coding (AMC), Multiple-input Multiple-output

Communications (MIMO), Hybrid Automatic Request (HARQ), fast scheduling, fast cell search, and advanced receiver design.

- *High-Speed Uplink Packet Access (HSUPA)*. It is a data access protocol for mobile phone networks, similar to HSDPA.

Mobile middleware is a layer of software that is used by an application so that it can connect to different wireless networks and operating systems transparently. Wireless Application Protocol (WAP), is the major standard developed by the WAP Forum, which allows the development of applications that are independent of the underlying wireless technology and is based on the Internet client/server architecture (Hunter, 2000).

2.4.2 Mobile Technologies

Cai *et al*. (2005) shows the need for multiple domain and device-aware representations of the geographical data to support the paradigm shift towards ubiquitous computing. Mobile technologies enable users to accomplish their tasks on-site using flexible, lightweight and wearable devices as seen by Sanfilippo *et al.* (2005). Mobile devices come in a variety of forms and processor types, with varying screen sizes and different input methods. Their major restrictions regard to limitations in disk space, memory, battery capacity, and the intermittent and varying connectivity to wireless networks. Mobile GIS applications integrate specific data acquisition, mapping and spatial analysis tools into applications packages or components that are only loaded on an as-required basis (Tao and Yuan, 2000). Therefore, a mobile GIS application should support a number of primary and subordinate functions (Herring, 2007):

- *Primary Functions:* Mapping and navigation; Data collection, query, and updating; Remote data access and management; Remote functional component access and integration; and Location Determination by Global Positioning Systems (GPS) (Figure 2.7);
- *Subordinate Functions:* Speech to Text; Automatic time stamping; Report generation; Two way messaging; and if speech is enabled, telephone communication.

Figure 2.7 A Global Positioning System (GPS) Mobile Handheld Device.

Source: www.wikipedia.org.

Herring (2007) also discusses that mobile software applications should:

- Provide the user with the ability to gather information and execute functional activities.

- Provide quick access to external data, update the data stored on the mobile device, and synchronize the data with the external datasets.
- Be able to be used while in motion, uncomplicated to learn, easy to customize and facilitate self-reliance.
- Be able to handle a large number of users concurrently.
- Support local and central database query, as well as the synchronization of information and two-way messaging.
- Be able to seamlessly integrate with existing information systems, without requiring any changes to be made.
- Support standard network security mechanisms that provide full authentication and security for access to the device as well as the network.

2.4.3 Location Systems

Location awareness is an important feature to many applications of mobile devices, so that they can retrieve, filter and present information depending on their own position in space (Butz *et al.*, 2000). According to Welch *et al*. (2002) the ideal location sensing system should be small, self-contained, complete, accurate, fast, immune to occlusions, robust, tenacious, wireless and cheap.

Hightower and Borrielo (2003) survey different features of a location aware system as follows:

- It provides either physical coordinates or symbolic designations.
- It is either absolute: two devices will report the same coordinates for the same location; or relative: each device has its own frame of reference, reporting positions in relation to itself.
- It must be accurate in regard to the distances within it can determine a location; and precise, in regard to how often can we expect to get that accuracy.
- Location of objects is variable: GPS can serve an unlimited number of receivers worldwide, but electronic tag readers cannot read any tag if more than one is within range.
- Its scale is variable: it may be able to locate objects worldwide, within a city, in a particular building, or in a single room.

Location awareness implies tracking either through GPS, radio bearing or conventional ultrasonic, magnetic or infrared tracking systems (Butz *et al.*, 2000).

Butz (2004) discusses two different approaches regarding the degree of activity allocated to the device. One approach puts the mobile device in charge of determining its position and selecting, retrieving and displaying the appropriate information (Fitzmaurice, 1993). In this context, active or passive markers are placed in the environment (Rekimoto and Ayatsuka, 2000; Billinghurst *et al.*, 1998), in order to be scanned by the mobile device to get information about its position in space and, then, retrieve, filter and present information appropriate to its position. Examples of this approach are the works with GPS of Feiner *et al*. (1997), and

Guven and Feiner (2003); the location aware tourist guides based on GPS tracking and/or augmented reality output facilities by Zipf and Aras (2002), Feiner *et al.* (1997), Wahlster (2001), and Cheverst *et al*. (2000); and the infrared markers used to mark exhibits in museums from Bieber and Ide (2002), and Oppermann *et al*. (1999). Another approach uses the fact that simple devices only receive information within a certain range. Electronic museum guides are one well known example, resulting in localized information that can only be received within the room where infrared or weak radio transmitters are placed. Another example is the use that cellular service providers are doing of the position of mobile phones in order to charge their customers different rates depending on their location.

Besides these two approaches there is a spectrum of location aware systems, as location awareness can be distributed between the device and the environment, each contributing its share. An example is the ParcTab (Figure 2.8), which does a certain amount of computation on the device, mainly display and interaction, but cannot function without an intelligent infrastructure (Want, *et al*., 1995).

For these different contexts tracking systems vary from outdoor environments (You *et al.*, 1999; Azuma *et al.*, 1999; Benedicto *et al.*, 2000), to indoor conditions (Priyantha *et al.*, 2000; Yokokohji *et al*., 2000).

Figure 2.8 ParcTab.
Source: http://sandbox.xerox.com/parctab/.

Butz (2004) also identifies as prevailing examples within the spectrum of existing systems the GPS car navigation and the GPS tourist guide (Baus *et al.*, 2002), the cellular phone Location Based Services (LBS), the infrared beacons (Bieber and Ide, 2002; Want *et al*., 1992; Harter and Hopper, 1994), and the broadcast networks (Want *et al*., 1995; Bahl and Padmanabhan, 2000; Harter *et al.*, 1999; Priyantha *et al.*, 2000).

3

Visualization

3.1 Introduction

Vision is the primary source for derivation of knowledge from real-world data (Wade and Swanston, 1991). Visualization is employed extensively in data presentation as well as in data analysis (Tukey, 1977). Some applications, including environmental applications, demand the combination of Geographical Information Systems (GIS) and visualization (Robertson and Abel, 1993). Integrating both systems in a working environment should add user-friendliness, interactivity and immersion to the visualization process, promoting a better insight into the data. Transparent integration of Virtual Environments (VEs) provides interaction with spatial information in general, and with GIS in particular (Neves *et al.*, 1999).

3.2 Information Visualization

Information visualization can be defined as the use of computer-supported interactive visual representation of abstract data to amplify cognition (Card *et al.*, 1999). The abstract characteristic of the data is what distinguishes information visualization from scientific visualization. Information visualization is more likely to be used to display database content than output of models or emulations, but this distinction is not always important. The display of geo-referenced data is often a hybrid visualization that combines abstract and concrete data (Plaisant, 2005). Examples of information visualization include maps, from the Portuguese explorations in the XVI century (Tufte, 1983) to the interactive HomeFinder application (Figure 3.1), which introduced the concept of dynamic queries (Ahlberg and Schneiderman, 1992).

The production of information visualizations involves the transformation of data into visual representations. These procedures rely on the creation of synthetic experiences that take into account human perceptual and cognitive capabilities, human variations, and task characteristics (Card *et al.*, 1997). Bertin (1981), Tufte (1983, 1990) and Marcus (1995), among others, have included into visualization principals some guidelines followed in psychology, such as: the *number seven plus or minus two* principle, which is related to the limits on the human capacity for processing information, and is applied to the number of colours that can be used in visualization (Miller, 1956); the concept of foreground and background, related to the separation that people are able to make between objects in an image; the grouping of objects that have similar visual characteristics; the grouping of objects that are closer in an image; and the continuity principle, which means that observers tend to complete objects in an image (Goldstein, 1999).

Information visualization aims to provide compact graphical presentations and user interfaces for interactively manipulating large numbers of items, possibly extracted from far larger datasets (Card *et al.*, 1999; Spence, 2001; Ware, 2000; Chen, 2002; Bederson and

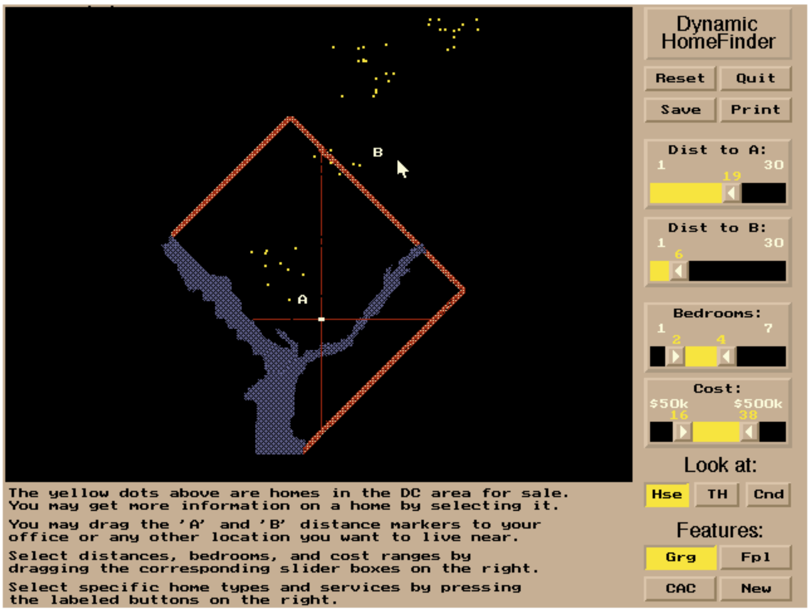

Figure 3.1 The HomeFinder Application.

Source: www.cs.umd.edu/hcil/spotfire.

Shneiderman, 2003). Also sometimes called visual data mining, it uses the enormous visual bandwidth and the remarkable human visual system to enable users to make discoveries, take decisions, or propose explanations about patterns, groups of items, or individual items. Information visualization focuses on data sets lacking inherent two or three dimension semantics and therefore also lacking a standard mapping of abstract data onto the physical space of the paper or screen. Techniques to visualize such data sets, including x-y plots, line plots, and histograms, are useful for data exploration but are limited to relatively small low-dimensional data sets (*Plaisant, 2005)*. There is, however an infinite number of possibilities to project high-dimensional data onto the two dimensions of a standard display. Projection Pursuit (Huber, 1985) attempts to locate projections that satisfy some computable quality of interest. A particular projection pursuit technique known as the GrandTour (Asimov, 1985) aims at automatically finding interesting projections or at least helping the user to find conclusion. A large number of information visualization techniques have been developed over the past decade, allowing visualizations of ever larger and more complex, or multidimensional, data sets (Keim, 2001; Soukup and Davidson, 2002).

Visualization datasets have two properties (Schroeder *et al*., 1998): structure and data attributes. The structure is characterised by topology and geometry. Topology is the set of properties that does not change with transformations such as rotation, translation, and scaling. Geometry refers to the coordinates of a polygon. The structure of a dataset consists of cells and points, where data values are known. The cells specify the topology, while the points specify the geometry. The datasets used in visualization may be classified according to their structure: regular or irregular. Regular or structured datasets can be implicitly represented in computerised visualization systems. Irregular data must be explicitly described due to their lack of pattern.

The attributes may be associated to cells or points. Data attribute types include (Schroeder *et al*., 1998):

- *Scalars.* Examples are temperature and elevation, valued at points of the dataset.

- *Vectors.* Magnitude and direction define vector data. Examples are sea currents and particle trajectories.
- *Normals.* These are vectors with magnitude equal to 1. They are often used to control the shading of objects and may also be applied to control the orientation and generation of cells primitives.
- *Texture.* This is defined by regular arrays of colour, intensity, and/or transparency values that provide extra detail to rendered objects. The draping of polygons with photo textures is an example of texture mapping.
- *Tensors.* Tables describe tensors with dimensions specified by their rank. A tensor of rank 0 is a scalar, rank 1 is a vector, rank 2 is a matrix, and rank 3 is a 3D rectangular array. Tensors are used to represent electromagnetic fields (Santos, 1994).

In information visualization, data is converted into graphical primitives (points, lines, polylines, and polygons). This conversion includes three stages: filtering, mapping, and rendering (Foley *et al.*, 1990), which correspond to the Haber and McNabb's (1990) Information Visualization Reference Model (Figure 3.2). In it, visualization is seen as a pipeline of processes, through which data flows from the source as raw data to the destination as image. Filtering is the extraction of features or reduction in quantity of data by computing derived quantities (Rhyne, 1997); mapping is the conversion of the resulting data into graphical primitives; and rendering generates a visible image from this geometrical information (Wood *et al.*, 1995). This model has formed the basis of many popular visualization systems, such as IRIS Explorer and IBM Open Data Explorer.

The algorithms used to transform and map data include geometric transformations that change geometry but not topology (translation, rotation, and scale of the points of a polygonal dataset), attribute transformations that convert attributes from one form to another or create scalars from input data, and combined transformations that change the dataset

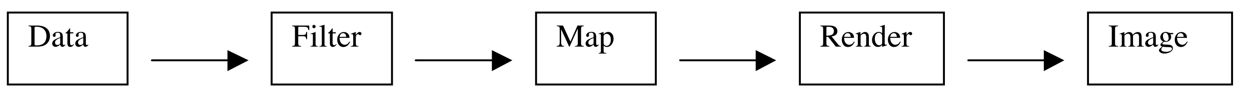

Figure 3.2 Haber and McNabb Visualization Reference Model.
Source: Haber and McNabb (1990).

structure and attributes (Schroeder *et al*., 1998). Algorithms may also be scalar or vector, regarding the attributes they operate on.

In environmental visualization, the most common datasets are structured point datasets, polygonal datasets, structural grids, unstructured grids, and unstructured points. For the visualization of multidimensional environmental data sets, glyphs are often used, for their size, shape, colour, and texture and can each be utilised to represent a variable in the data (Camara 2002). Glyphs are used to represent a local distribution of values or the structure of a complete dataset, being affected by input data and altering the pictorial object in response to data. Glyphs may be displayed as arrows, spheres, needles or any other suitable iconic representation (Figure 3.3).

Examples of visualization of environmental data sets include Kazafumi (1989) on impact assessment visualizations, Kruse *et al*. (1992) on space imaging, DeGloria (1993) on soil behaviour visualization, Wolff and Yeager (1993) on natural phenomena visualizations, Fedra (1994) on water and air pollution visualization, Fuchs (1994) on marine data

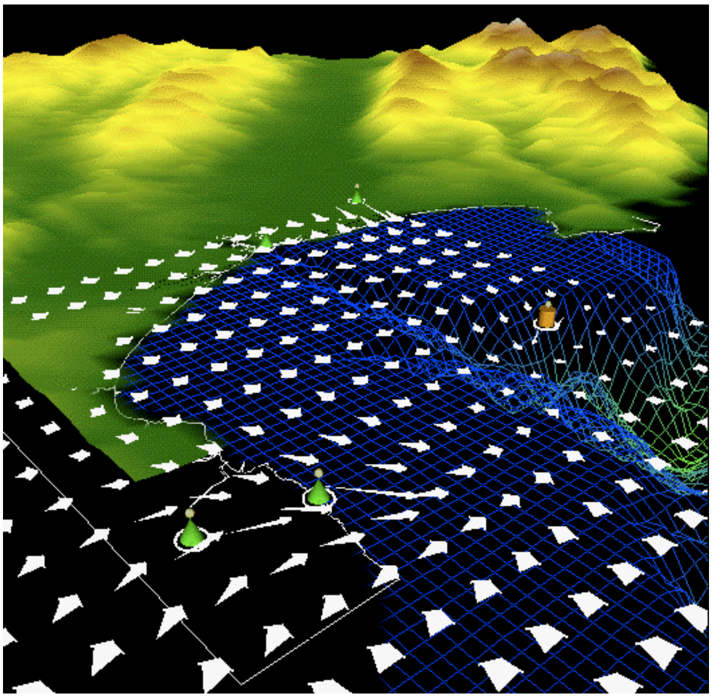

Figure 3.3 Uncertainty Glyphs 3D Visualization.
Source: www.slvg.soe.ucsc.edu/uglyph.

visualization, Delmarcelle and Hesselink (1995) on flow visualization, Owen *et al.* (1996) on groundwater systems visualizations, and Liddel and Hansen (1997) on soil ecosystems visualization.

3.3 Data Types

What follows is a survey not only of the types of data dealt with in information visualization, but also its possible organization and display.

3.3.1 Uni-dimensional Data

Linear data types include lists, documents, program source code, and the like that are organized sequentially. User tasks include overview, scrolling and selection (Eick *et al.*, 1992; Shneiderman, 1996). Spiekerman and Ginger (1993) discuss rules for legibility and effectiveness in the typographic level of text, concluding that the number of type of fonts and sizes should be limited as the use of type weights and styles.

Most invariant data related to environmental phenomena are associated with data distributions that can be represented through histograms, bar graphs, quantile plots and box plots (Cleveland, 1993; Tukey, 1977).

Time series are a very common one dimensional (1D) data, used from line plots to summaries of heterogeneous data such as LifeLines (Plaisant *et al.*, 1996). Frequent tasks include finding all events before, after or during some time period or moment, and in some cases comparing periodical phenomena (Carlis and Konstan, 1998). Space–time data have also been a focus of attention in geovisualization (Szego, 1987; DiBiase *et al.*, 1992; Kraak and MacEachren, 1994; Kwan, 2000; Andrienko and Andrienko, 2004).

3.3.2 Multi-dimensional Data

Most relational and statistical database contents are manipulated as multi-dimensional data, in which items with n attributes become points in an n-dimensional space, being represented by dynamic scattergrams with each additional dimension controlled by a slider or button using dynamic queries (Williamson *et al.*, 1992; Ahlberg and Shneiderman, 1994)

Planar data (2D) can be represented by geographic maps, floor plans, and newspaper layouts, used to find items and paths between items (Plaisant, 2005).

The benefits of three dimensional (3D) visualization have been discussed, among others, by Nielson *et al*. (1997), Wise *et al*. (1995), Cockburn and McKenzie (2002), Kraak (1989) and Dorling (1992). In 3D applications, users must understand and control their position and orientation when viewing the objects, and must be able to compensate for problems of occlusion (Shneiderman, 1996). Parallel coordinates plots are a multi-dimensional technique that has shown to be a powerful analysis tool. It enables the exploration of problems with a number of dimensions limited only by the size and resolution of the monitor (Inselberg and Dimsdale, 1987, 1994; Inselberg, 1997).

Another procedure is the use of the *worlds-within-worlds* scheme for visualizing multivariate functions. This method relies in taking an infinitely thin slice of the world perpendicular to the constant variable's axis, reducing the world's dimension, and enabling the manipulation and display of the resulting slice in 3D. To retrieve the higher dimensions, a 3D world is embedded in another 3D world. The position of the embedded world's origin relative to the containing world's coordinate system specifies the values of up to three variables that were held constant in the process of slicing (Beshers and Feiner, 1993).

CAVE Automatic Virtual Environment (Figure 3.4) enables the exploration of water chemistry data from sampling sites, interacting with data in a highly immersive 3D virtual reality environment through paint-brushing data with different colours and geometric representations. Any viewpoint can also be achieved, eliminating occlusion in 3D scatterplots (Cruz-Neira *et al.,* 1992; Cook *et al.*, 1998).

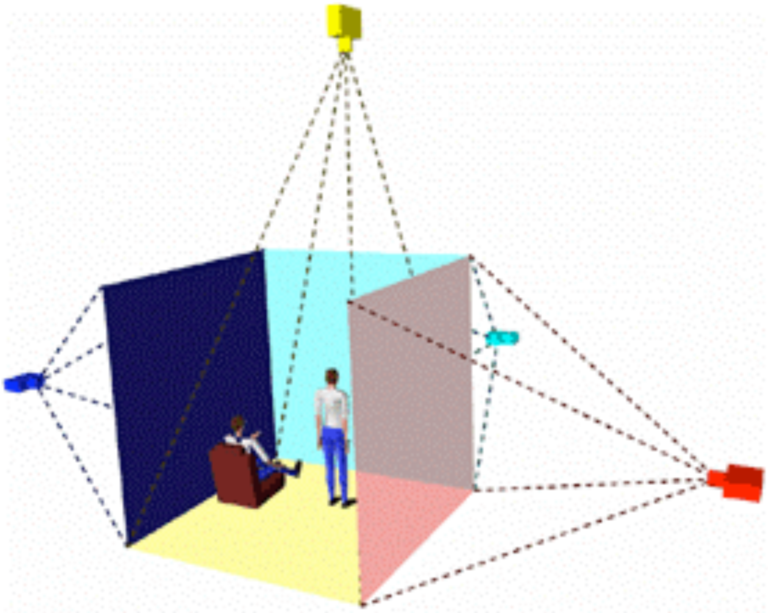

Figure 3.4 Cave Automatic Virtual Environment.

Source: www.wikipedia.org.

Other examples in multidimensional data visualization include the Table Lens (Rao and Card, 1994; Inxight Software Inc., 2002), which uses a spreadsheet metaphor; the VisDB for multi-dimensional database visualization (Keim and Kriegel, 1994); interactive mosaic displays (Friendly, 1994; Theus, 2002a,b); the Attribute Explorer (Tweedie *et al*., 1996); and the scatterplot matrices of Becker and Cleveland (1987). Interactive geovisualization software also utilizes multidimensional visualization techniques (Andrienko and Andrienko, 1999a–e; Gahegan *et al*., 2002a, b; MacEachren *et al*., 2003a, b).

3.3.3 Hierarchical Data

Hierarchies or tree structures are collections of items, in which each item, except the root, has a link to one parent item. Examples include taxonomies, file structures, organization charts and disease classifications. Items and the links between parent and child can have multiple attributes. Tasks can be topological or attribute based. Interface representations of trees can use the indented labels used in tables of contents or node-and-link diagrams (Plaisant, 2005).

Examples include the Hyperbolic Tree (Lamping *et al*., 1995), the SpaceTree (Plaisant *et al.,* 2002; Grosjean *et al*., 2002), and the Treemap, as in Figure 3.5 (Johnson and Shneiderman, 1991; Bederson *et al*., 2002; Shneiderman, 1998).

3.3.4 Network data

When relationships among items cannot be captured conveniently with a regular tree structure, items are linked to an arbitrary number of other items in a network. Common representations include node and link, and square matrices of items with the value of a link attribute in the row and column representing a link (Rodgers, 2005). It is used in a number of geographic applications and is being incorporated into software for geovisualization (Mountain, 2005; Fairbairn, 2005). Networks are relevant for environmental applications as they represent physical phenomena and provide metaphors for non-physical data. Network types that may be of interest include grids, trees, circuits, and weighted graphs (Camara, 2002). Shneiderman (1996) and Card *et al*. (1997) discuss problems associated with the visualization of networks, such as display clutter, node positioning, and the perceptual tensions occurring when nodes that are closer are not related. Interactive techniques for

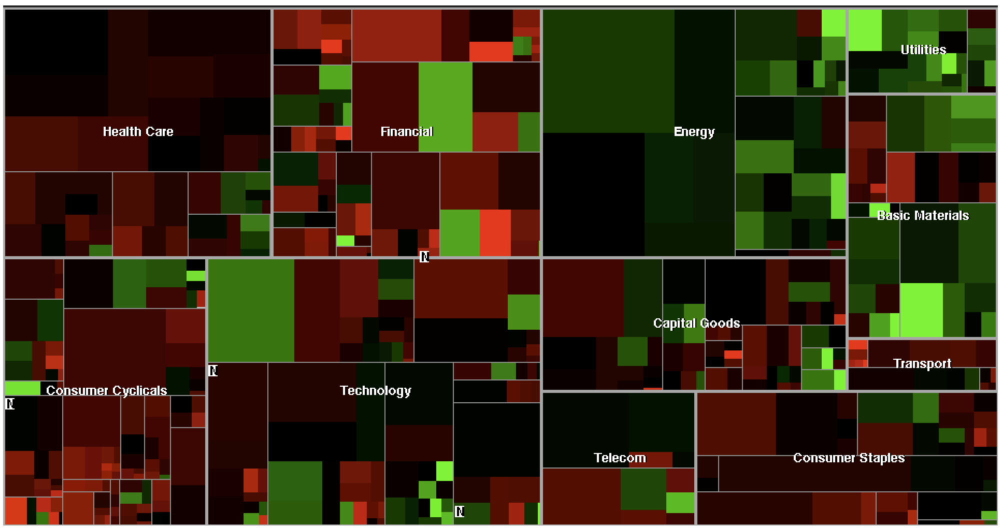

Figure 3.5 Treemap.
Source: www.smartmoney.com.

displaying networks include: moving and hiding nodes or edges, geometric zooms or pans, the use of hierarchical graphs, multiple views, database style queries, and animation techniques to illustrate dynamic phenomena in a network (Jones, 1996).

3.4 Task Types

Having considered the range of data types available along with some methods that have been developed for graphically representing them, we can consider a number of high level tasks that apply to all data types.

3.4.1 Overview Task

Gaining an overview of the data might include gauging the number of items and the range and distribution of the attribute values, or estimating how much things have changed since last time the user reviewed the data. Overview strategies include zoomed-out views adjoining the detail views (Ware and Plumlee, 2005). A movable field-of-view box can be used to control the contents of the detail view. Intermediate views allow larger zoom factors. Another popular approach is the fisheye strategy originally described by Furnas (1986). It provides overview and details in a single combined view by using distortion based on a degree of interest function. It is effective when zoom factors are small and deformation is acceptable to users.

3.4.2 Zoom Task

Users need to control the zoom focus and the zoom factor. Smooth zooming helps users to preserve their sense of position and context *(Ware and Plumlee, 2005).* Piccolo is a popular zooming user interface toolkit that uses semantic zooming (Bederson, 1994; Bederson *et al*., 2000). Semantic zooming is commonly used with maps, where the same area can be displayed with different features and amount of details at different zoom ratios (Perlin and

Fox, 1993; Weibel and Jones, 1998). Constant density zooming is an example of technique to maximize the number and readability of items on the display (Woodruff *et al*., 1998). Wood (2005) and Dollner (2005) use mipmapping to display surface characteristics according to the scale at which any part of a surface is viewed in a real-time 3D application.

3.4.3 Filter Task

Dynamic queries allow users to quickly focus on their interests by eliminating unwanted items. Other techniques include sorting, grouping or highlighting followed by hiding, or locating items similar to an item of interest (Theus, 2005).

3.4.4 Details-on-demand Task

Once a collection has been trimmed, users need to review the details of single items or groups of items. The usual approach is to simply click on an item and review details in a separate window. Eccentric labelling is an approach in which geovisualization techniques and those of information visualization are integrated (Fekete and Plaisant, 1999).

3.4.5 Relate Task

Linking and brushing techniques (Cleveland, 1994) and the Influence Explorer (Tweedie *et al*., 1996) emphasize the exploration of relationships. Many applications combine multiple visualization techniques that are tightly coupled (Roberts, 2005; Andrienko *et al.*, 2005; North *et al.,* 2002).

3.4.6 History Task

Keeping the history of actions allows users to retrace their steps, save useful exploration and apply them to updated datasets later on. Roberts (2005) considers these issues at an operational level and Gahegan (2005) addresses the conceptual, scientific and motivational challenges that underlie support for saving and sharing entire analysis strategies.

3.4.7 Extract and Report Task

Users often need to save subsets of the data or particular views of the data into reports, or publish data with a simplified subset of the tool's features for others to review.

3.5 Geovisualization

For MacEachren (1994), geographic visualization is characterized by the manipulation of graphic data representations by individuals who seek to construct new knowledge. Maps provide the geographical data that characterise objects on their position with respect to a known coordinate system, their physical attributes associated with the geographical position, and their spatial relationships with surrounding geographical features. MacEachren (1995) and Kraak and Ormeling (1996) provide a review on traditional cartographic representations, such as cloropleths, isopleths that use the contour plot concept, dot maps and flow maps (Figure 3.6).

Aerial photos and satellite images are also means for realistic visualizations, after classification of spectral data associated to terrains. As MacEachren and Kraak (1997) have commented, there are several trends in spatial visualization and interaction that go beyond the use of traditional maps and remote sensing images, such as:

- The association of linked views to maps including three dimensional models, graphs and databases to maps. Examples are provided by Cook *et al*. (1997) and Anselin (1999), linking mapping and exploratory data analysis software; and Shiffer (1993), augmenting geographical information with multimedia.
- The superimposition of air pollution plumes on maps, aerial photographs, or satellite images, as discussed in Boice (1992) and Chakraborty and Armstrong (1996). Monmonier (1999) presents related visualization examples from weather forecasting.
- The use of animation in dynamic mapping, as proposed by DiBiase *et al*. (1992) and Mitas *et al*. (1997).
- The visualization of uncertainty of spatial information.

- The exploration of three dimensional representations of the terrain. These may be digital terrain models draped with photo textures, or virtual reality representations.
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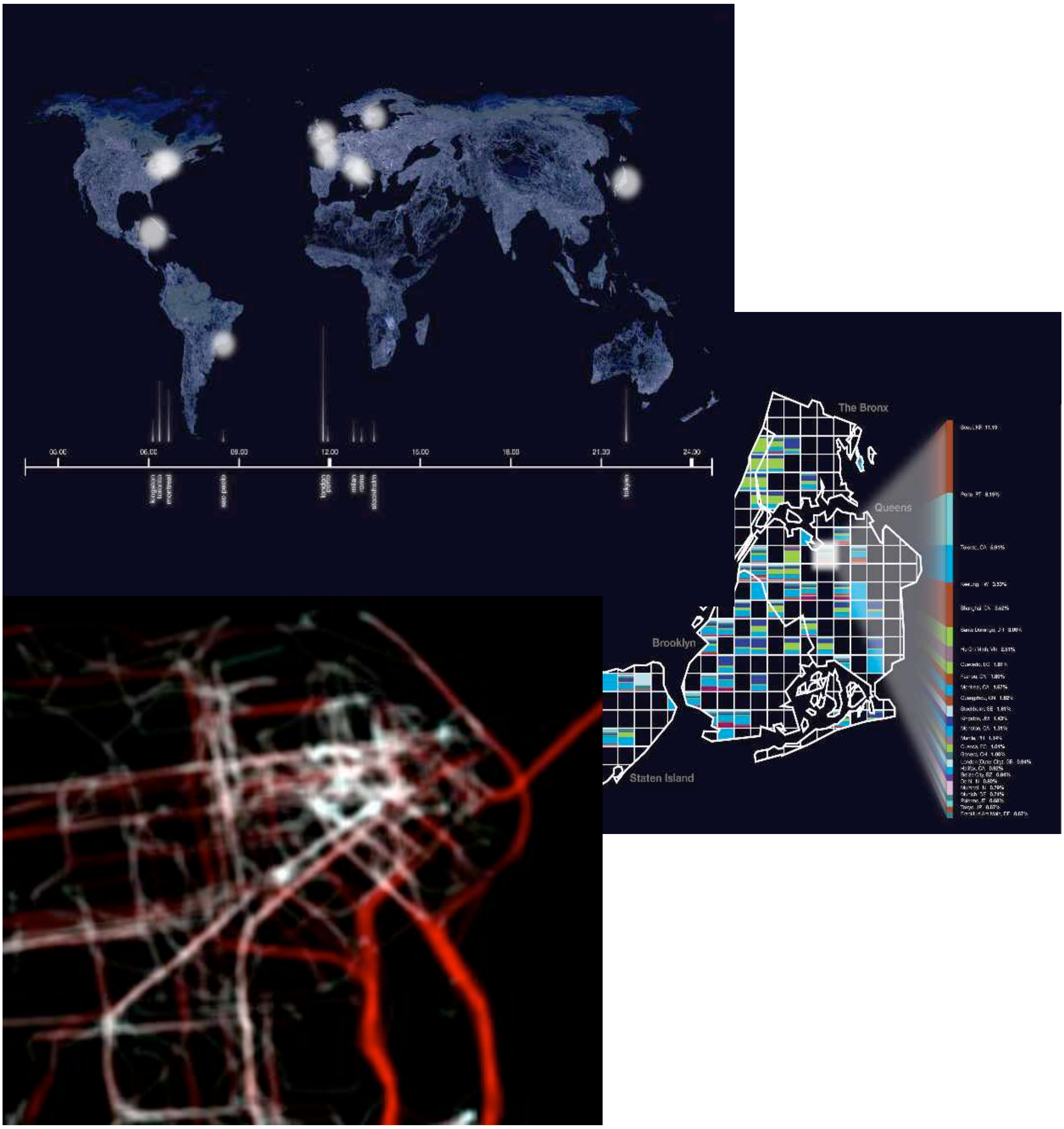


Figure 3.6 (Downwards) Dot Map, Cloropleth Map, Flow Map.

Sources: http://senseable.mit.edu/nyte; http://cabspotting.org

3.6 Virtual Reality

The use of visualization methods in the analysis of geo-referenced data, based essentially on static models, restrict the users' visual analysis capabilities (Dioten and Kooy, 1995). The use of Virtual Reality (VR) provides the ability to change viewpoints and models dynamically, overcoming those limitations (Neves *et al*., 1999).

VR technologies provide real time generation of quasi realistic three dimensional graphics and sound, allowing sensory immersion. Virtual worlds or virtual environments (VEs) facilitate human-computer interaction with environmental decision support systems by the use of realistic representations and direct manipulation of virtual objects (Burdea and Coiffet, 1994). VEs are those that result from the interaction between the cognitive level of the human being and the visual and audible images produced by the computers. They can be used to organize, represent and manipulate multi-dimensional data, in plain images, 2.5-D models and 3D immersive environments (Jacobson, 1994). VEs' displays fall under non-immersive and immersive categories. Non-immersive solutions include the use of glasses where the lenses consist of fast shutters synchronised to the computer display (Jones, 1996), while immersive approaches include Head-mounted Displays (HMDs), the CAVE Automatic Virtual Environment (Cruz-Neira *et al*., 1992), and the Immersadesk (Reed *et al*., 1997). The Virtual Reality GIS, developed by Pajarola *et al.* (1998*)*, maintains three dimensional terrain data in vector form (such as surface triangulations), raster data (such as those from satellite images and topographic maps), and non-geometric data (such as population counts of cities). It allows users to move through the scene in real-time by means of a standard input device, such as a mouse, and to interact with the GIS through a point-and-click interface with pop-up windows for non-geometric data.

With GIS acquiring powerful 3D output capabilities, the use of VEs is a given for geographic visualization (Faust 1995). Kumaradevan and Kumar (2001) describe how VR interfaces can be used for distributed GIS. Koller *et al*. (1995) report on the development of Virtual GIS, a system with immersive capability for navigating and understanding complex and dynamic terrain-based databases. Germs *et al*. (1999) discuss how VEs can be integrated in more traditional outputs, such as plan maps and bird's-eye views, to provide a multi-representation system. Fairchild (1993) has reported significant work in the use of visualization for information management and McGreevy (1993) discusses the use of VR for planetary exploration. Applications of VEs to environmental quality problems include visualizations of a water quality models (Wheless *et al*., 1996), visualizations of ocean circulation models (Gaither *et al*., 1997), decision support systems for water quality management (Camara *et al*., 1998), and the exploration of environmental data in a CAVE environment (Cook *et al*., 1998).

3.6.1 Virtual Reality and the WWW

A major tool to present 3D over the Internet is Virtual Reality Modelling Language (VRML), a high level object-oriented language for the description of scenes and behaviours of 3D objects and environments (Day, 1994; Zhu *et al*., 2003). Web 3D Geographical Information

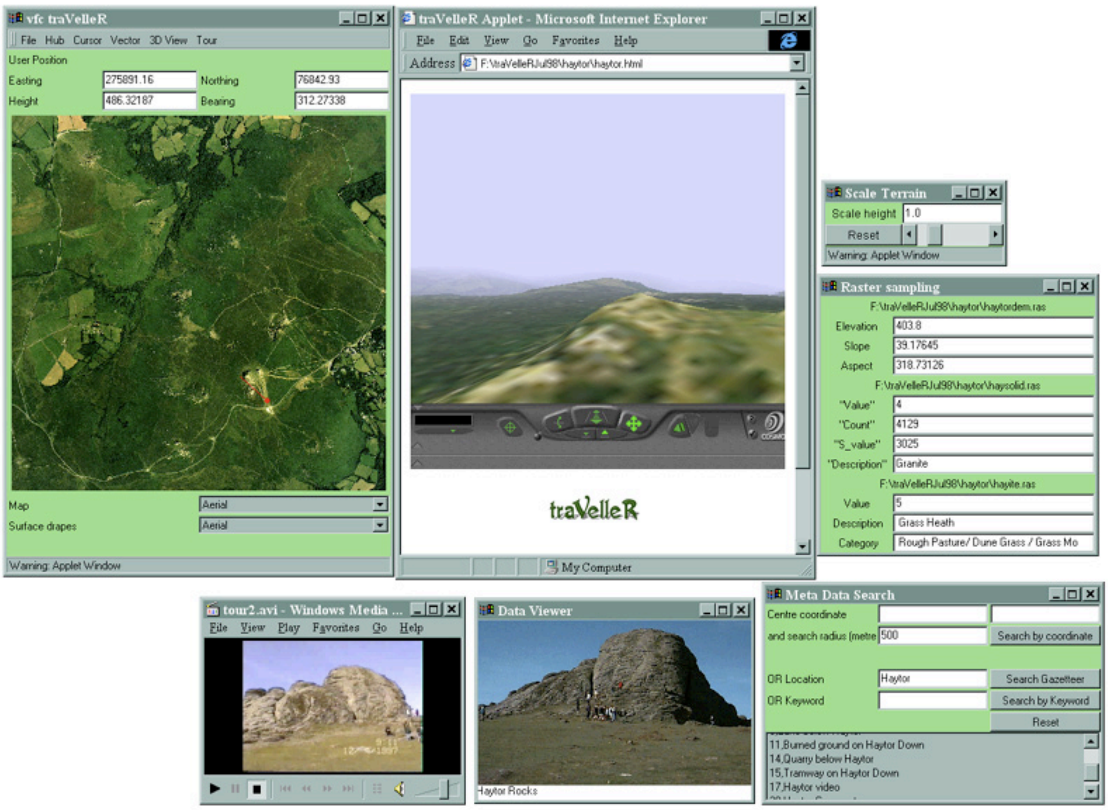


Figure 3.7 The Virtual Field Course's TraVeller Screen.
Source: http://www.geog.le.ac.uk/vfc.

Systems (GIS), supported by VRML, are cheap, platform-dependent, can provide interactive visualization and have high compatibility with other tools like Java (Liarokapis *et al.,* 2005). Moore *et al. (*1997) started the project of The Virtual Field Course which uses a VRML interface to explore a geographic database and multimedia resources fieldwork areas (Figure 3.7). Shan (1998) integrated Computer-aided Design (CAD), Computer-aided Manufacturing (CAM), Digital Product Simulation (DPS), and GIS data in a desktop environment based on the 3D Web, to model and render terrain, buildings and their appearance. Coors and Jung (1998) created GOOVI-3D, a prototype system that provides access and interaction with a 3D spatial database over the Web, by proposing two lightweight extensions of VRML: an integrated name dictionary management and a Structured Query Language (SQL) node. Lee *et al.* (1998) proposed a Web 3D GIS with spatial analysis functionality, featuring design of the module of Spatial Operation Manager with operations such as: near analysis, 3D buffering, distance measurement and lantern selection. Geo-related Web 3D applications have also been developed in the area of architectural and archaeological restoration (Caiani *et al.* 2001), meteorological service (Chan *et al.,* 2001) and ocean science (Campbell *et al*., 2002 and McCann, 2002).

3.7 Augmented Reality

Milgram and Kishino (1994), define a Virtuality Continuum, in which, at one end, there are real environments and, at the other end, virtual environments (VEs). Between these two extremities real and virtual objects are presented together, creating a mixed reality. Augmented Reality (AR) is a part of the mixed reality, in which there is the combination of a real scene viewed by users and a virtual scene generated by a computer. The latter augments the real scene with additional information, interactively and in real time, allowing users to examine and work with the physical world, while receiving additional information about the objects in it (Ratti *et al*., 2004; Azuma *et al*., 1997). An augmented reality system can also enhance senses like touch, hearing and smell, and instead of adding virtual objects to the scene, real objects can be removed. AR interfaces can enhance the cues already present in face-to-face collaboration, making collaboration more effectively than in an immersive VR interface (Hedley *et al.,* 2002). It can be applied to environmental management, computer-aided surgery, repair and maintenance of complex engines, facilities modification, and interior design. One of the greatest benefits of AR interfaces is that they can be integrated into the existing workplace and combined with other more traditional interface technology. The EMMIE system is a hybrid user interface that merges information in an AR headset with data shown on monitor and projection displays (Butz *et al*., 1999). Users can move virtual objects from being overlaid on real world to being placed on a desktop monitor. Wellner's (1993) Digital Desk illustrates the efficiencies of augmenting paper-based office production with digital tools and methods for storage. Systems such as the Phantom Arm (SensAble Technologies, 2003), when combined with virtual environments or holography, allow for highly convincing interactions. Agrawala *et al*. (1995) have developed methods for painting directly on the surfaces of complex 3D geometries while Raskar (1999) and Bandyopadhyay *et al*. (2001) have looked into the possibilities for animating computational projection and highlighted some of the difficulties that arise when projecting from multiple sources. Ishii *et al*. (1997) introduced three design projects: metaDESK, transBOARD and ambientROOM. These projects attempt to turn digital information from cyberspace into tangible media in the physical world using interactive surfaces, coupling of bits with graspable physical objects, and ambient media for background awareness. For that matter, ambientROOM tries to make seamless transition between foreground and background perception. TransBOARD explores the concept of interactive surfaces, absorbing information from the physical world and transforming it into bits, and distributing it into cyberspace. In order to distribute the information, transBOARD uses a networked and digitally-enhanced physical whiteboard to achieve its intents. Underkoffler and Ishii (1999) developed an Urban Design Workbench that uses digitally augmented tagged physical objects to represent buildings that can be rearranged to facilitate the process of urban design. A similar system has also been coupled with a GIS by Coors *et al*. (1999).

AR in GIS can simultaneously superimpose various types of multimedia information including 3D models, images, text and sound, allowing the users to visualise the geographical information in a demonstration mode (Reitmayr and Schmalstieg, 2004). Takuma *et al*. (1997) describes an application of AR to GIS, in which the system allows the retrieval of information from a database by clicking real objects in live video images. Ghadirian and Bishop (2002) report on a similar system developed for monitoring environmental change, while Pasman *et al*. (1999) address some technical issues in accurately overlaying virtual information on real-world views. Vidente (Figure 3.8) is a handheld outdoor system in which users are provided with an intuitive visualization of the local underground infrastructure on a handheld device. The visualization is achieved by continuously overlaying a video stream of the current environments with georeferenced 3D computer graphics, and real time adjustment according to position and orientation of the handheld device. Other examples of AR visualization techniques for presenting

geographical information can be found in the works of Hedley and Billinghurst (2002), Hinn *et al.* (2002), Ghadirian and Bishop (2002), Höllerer and Feiner (1999) and Bederson (1995).

Figure 3.8 Vidente.
Source: http://www.vidente.at.

3.7.1. Augmented Reality Interfaces

According to Cartwright *et al.* (2001) there is a need for more natural interfaces to geospatial information environments, so that they become accessible to more people. Elvins and Jain (1998), and Oviatt and Cohen (2000) have stated the importance of adequate input/output representations in GIS, through the discussion of multimodal interfaces in GIS, and the compatibility of the users' and system's conceptual models.

Azuma *et al*. (1997) points two main trends in Augmented Reality interaction research:

- The use of heterogeneous devices to leverage the advantages of different displays. Greenhalgh *et al*. (2001) developed different interfaces that illustrate several approaches to augmented reality interfaces (fixed and mobile telephones; PDAs, GPSs and wireless networks, combined to create a digital activity meter; augurscopes; and virtual shadows).
- Integration of the virtual and real world through the use of tangible interfaces.

The ultimate goal of an effective AR system is to enhance the users' perception and interaction with the real environment by superimposing the real world with 2D and 3D virtual information that appear to coexist in the same space as the real world (Azuma, 2001). The superimposed information can be presented in a number of different mobile display systems including head attached displays such as head-mounted displays and Head-Up Displays (HUDs) as well as other types of displays including Personal Digital Assistants (PDA) and 3G phones.

Tangible User Interfaces (TUIs) are increasingly accepted as an alternative paradigm to the more conventional Graphical User Interface (GUIs) (Ullmer and Ishii, 2000). They offer the ability to manipulate objects in space and aim to combine the benefits of physical and digital models in the same representation (Ratti *et al*., 2004). TUIs are extremely intuitive to use since they can give physical form to virtual information, facilitating direct manipulation of physical representations (Ishii *et al.*, 2004; Fitzmaurice and Buxton, 1997)). The intuitive manipulation of tangible user interfaces with the prospects of AR visualization is referred as tangible augmented reality (Hedley, 2002). Illuminating Clay and SandScape are TUIs developed by Ratti *et al*. (2004) aimed at solving the disjunction between physical and digital forms of representation and analysis, especially between the upstream of exploratory design and the downstream of analytical design (Figure 3.9 and 3.10).

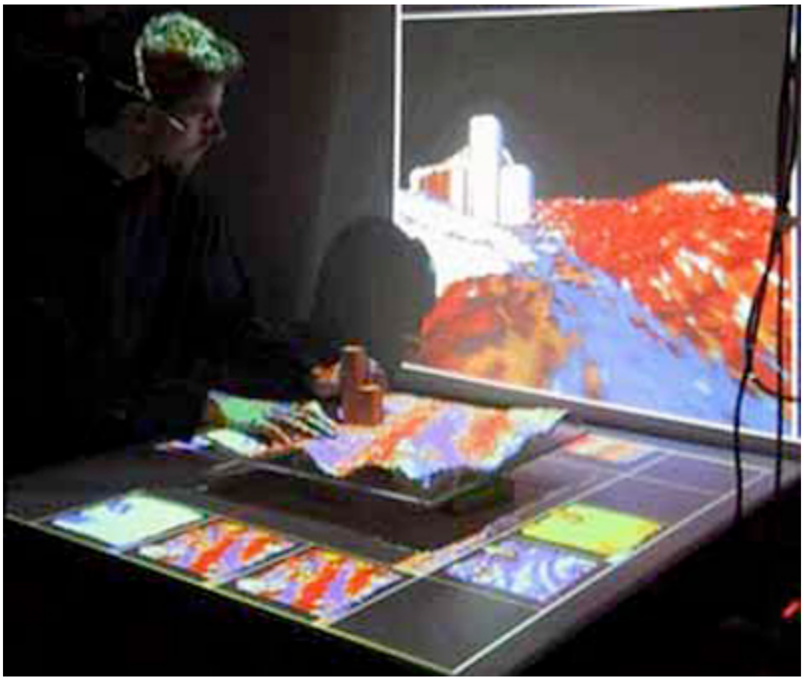


Figure 3.9 Illuminating Clay.

Source: http://tangible.media.mit.edu/projects/illuminatingclay/.

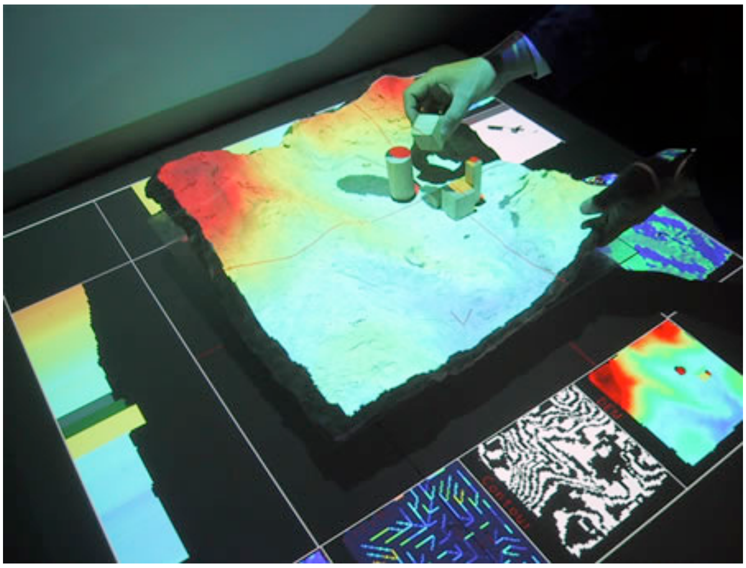


Figure 3.10 SandScape.

Source: http://tangible.media.mit.edu/projects/sandscape/.

AR can be done not just by adding visual information to environment but also by adding audio information. Audio elements can be important in transmitting changes in time and space, outlining outliers and extreme values, and representing distinct dimensions of multidimensional data. This can be done by means of associating sounds to data points, controlling sound attributes by data values, and triggering the sound on some event (Kramer, 1994; Barrass and Kramer, 1999; Burger, 1993; Begault, 1994). Sound can also help the user locate sources of information which are outside of the field of vision in VEs (Hereford and Winn, 1994; Shepherd, 1994).

According to Neves *et al*., 1994, sound becomes a more significant guiding factor than visual variables when immersed in VEs. There, the auralisation of pollutant levels can use surround sound to represent the water pollution level at a given place, and localised sound to guide users to the most significant concentrations of pollutant particles. Behringer *et al*. (1999) developed a system that overlays 3D objects, animations and text notes over a known object, so that device components can be queried using a voice recognition system and an animation of the component, and 3D spatial audio cues will be overlaid (Figure 3.11). Several uses of sound in the visualization of environmental or spatial phenomena can be seen in the works of Scaletti and Craig (1993), Shiffer (1993) and Krygier (1994).

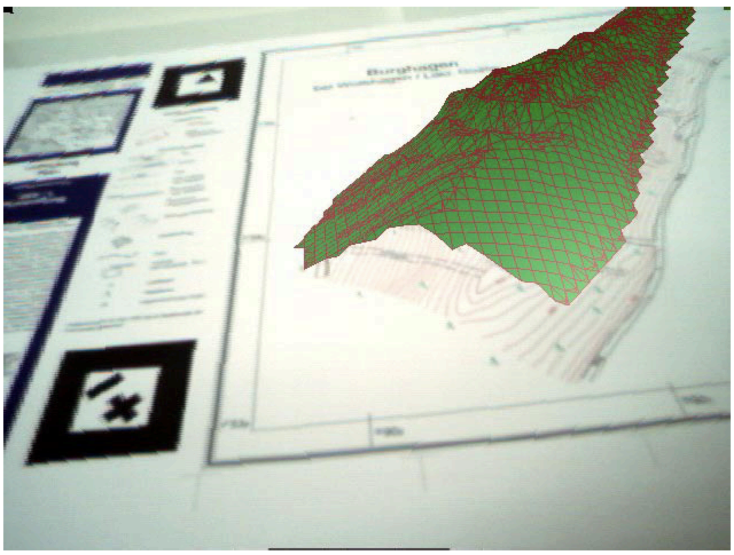


Figure 3.11 Overlay with DEM.

Source: www.ikg.uni-hannover.de.

4

Collaborative Environments

4.1 Introduction

Geographical information visualization technologies often involve not only perceptual and cognitive processes, but social ones. Having often to deal with data sets that are so large that thorough exploration by a single person is unlikely, participants need to learn from their peers when building consensus or making decisions around and about those data sets (Heer and Agrawala, 2007). Card *et al*. (1999) describe how visualization supports the process of sensemaking, in which information is collected, organized, and analyzed to form new knowledge and inform further action. Because sensemaking is often also a social process, visualizations must support social interaction (Heer and Agrawala, 2007). Examples of such collaborative scenarios can be found in business intelligence (Pirolli and Card, 1999), intelligence analysis (Pirolli and Card, 2005; Thomas and Cook, 2005), public data consumption (Dorling *et al.*, 2006), argument visualization (MacEachren *et al.*, 2004), and multimodal interfaces for geospatial information (McGee and Cohen, 2001).

Suthers *et al*. (2003) discuss that, in the collaborative dimension, the type of visually structured representations determines the data the user focuses on. Visualization, not being a pure presentation layer, plays a direct role as a Human-Computer Interface (HCI) by enhancing cognitive capabilities (Card *et al.*, 1999). Hetzler and Turner (2004) discuss that many existing visual analytical systems are data-centric, focusing on particular types of data and providing separate but linked environments for analysis of different types of information. Andrienko and Andrienko (2004) explored how information synthesis can enable annalists to handle dynamic information of all types in a seamless environment. Pinto *et al*. (2003) discuss how multiple representations of heterogeneous data can require different semantic models. Kersting and Doellner (2002) developed a technique for mapping 2D vector data directly onto geo-referenced geometries while keeping the semantics of the underlying data, showing that data representations could be merged into a combined form.

As suggested by Beeharee *et al*. (2003), it is fundamental for the user immersed in distributed virtual environments to experience a credible and sound shared world. A user-centred multimodal interface was presented by Agrawal *et al.* (2004), in which rule-based mapping of interactions was used to compose queries to the underlying data stores using gestures and speech recognition. Stasko *et al.* (2004) and Cadiz *et al.*, (2002) state that, in order to meet the requirements for an effective data exchange, any system must provide the proper scalability in terms of device configurations. This is necessary to ensure better interactive group collaboration and peripheral awareness of information. Work by Fekete and Plaisant (2002) has addressed the challenge of scaling visual representations of large data sets of discrete items without the use of aggregation techniques, investigating both visual attributes and interaction techniques. The system of Stolte *et al.* (2002) changes representations based on the semantics of the data, and hence it is possible to provide semantic, multiscale interfaces. The work of Shumilov *et al.* (2002) has introduced an open infrastructure for the processing of large complex spatio-temporal models, in which heterogeneous geodata and the tools for their modification and retrieval have been integrated into one distributed framework. Similarly, the work of Bolelli *et al.* (2004) provided an integration of heterogeneous GIS applications into a device-aware, collaborative distributed framework to support decisionmakers in crisis situations. Baudisch *et al.* (2003) notices that visualization systems should present all the relevant information required by a decision maker to efficiently and correctly comprehend and act in a complex situation, both on-site and in the office. Kapler and Wright (2004) found that systems which force a user to view information sequentially are time-consuming and error-prone. Greene *et al.* (2000) investigated a number of visualization and user interface techniques that have been developed to support coordinated views of both overview and detail.

4.2 A Taxonomy of Collaborative Tools

Groupware or Computer Supported Collaborative Work (CSCW) is computer-assisted coordinated activity carried out by groups of collaborating individuals (Baecker et al., 1995). Groupware may be defined as hardware, software and processes designed to aid in group related tasks such as basic communication, information sharing, decision making, scheduling/control, and analysis/design (Saunders, 1997). Johansen (1988) divided the approaches and computer aiding tools in the groupware arena into four categories including same-time same-place, same-time different-place, different-time same-place, and different-time, different-place (Table 4.1).

Table 4.1 The Time-Space Matrix.
Source: Adapted from Johansen (1988).

Same Time / Same Place Shared Screens. Group Decision Support Systems	**Different Time / Same Place** Interactive applications enabling annotation.
Same Time / Different Place Audio-Visual Conferences. Chat Systems. Multi-User Variants. Tangible Augmented Reality Interfaces.	**Different Time / Different Place** Electronic Mail Collaborative Database Systems Workflow.

4.2.1 Synchronous Collaborative Visualization

Research in multi-user visualization systems has largely focused on supporting either collocated or synchronous collaboration models. Systems supporting distance work have primarily focused on synchronous interaction, such as shared virtual workspaces and augmented reality systems that enable multiple users to interact concurrently with visualized data (Viégas and Wattenberg, 2006). From the standpoint of GIS, the most interesting tools for synchronous visualization are: shared screens, for disaster management, planning exercises, and environmental education; videoconferencing, for remote work; chat systems, enhancing participation; group decision support systems, for supporting major decisions; multi user domains, for environmental education; and tangible augmented reality interfaces, for enhanced collaborative visualization (Camara, 2002).

Shared Screens

Shared Screens can replace the analogue boards with the digital advantages: storage of information, replay of historic information, and access to current information and simulations. However, shared screens do present problems when large numbers of people want to interactively control the system, which for many functions, such as zooming or panning, is a technical impossibility. In a technical setting, a shared screen can be divided in a number of shared screens, if the system can be divided into as many subsystems. Each of the screens may have an associated projector, such as Interactive Works Spaces (Winograd, 1998), or each screen may also be a Liveboard (Figure 4.1) as proposed by Elrod *et al*. (1992).

Videoconferencing

An important quality of videoconferencing is the ability to see and hear others over long distances. Expensive technologies have been replaced over the years with affordable Internet technologies, like small cameras and audio systems coupled to personal computers and increased bandwidth (Schaphorst, 1996). With the Internet, systems like ClearBoard (Ishi and Kobayashi, 1992) enable the interaction, on the same screen, of users remotely located over a shared drawing. In UbiMedia (Buxton, 1995) the user is free from the camera focused interaction by placing a large number of cameras and monitors throughout the environment.

Chat Systems

Among the available chat facilities, Internet Relay Chat (IRC) is the most widespread, international and multilingual one (Harris, 1995). IRC is a form of real-time Internet text messaging or synchronous conferencing that is mainly designed for group communication in discussion forums, called channels, but also allows one-to-one communication via private message as well as chat and data transfers via Direct Client-to-Client. Chat facilities with simpler interfaces than IRC are widely applied today in any kind of websites that may convey users' synchronous discussions.

Figure 4.1 Liveboard.
Source: http://www.parc.com/.

Group Decision Support Systems

Group Decision Support Systems, use a controlled atmosphere, a defined process, and a bag of tools for supporting groups making major decisions (Saunders, 1997). The Controlled Atmosphere refers to a neutral environment where the meeting may proceed without interruption, where critical data is readily available, and where participants can effectively see, hear and respond to the each other. The Defined Process requires three key players: the process owner, a facilitator, and a technographer. The process owner is the person who must go forth with the decisions made in the decision room session. The process owner collaborates with the facilitator to establish a timetable and an agenda in advance of the actual meeting. The facilitator is responsible for keeping the meeting moving, staying on the agenda, assuring equal time for participants, and encouraging discussion. The technographer is an individual trained in the technical workings of the software. It is their job to move the data around as unobtrusively as possible during the actual meeting. The Bag of Tools provides capability for the group to set an agenda, and then to do brainstorming, filtering, classifying, and prioritizing of the issues at hand. They provide anonymity, complete record keeping, parallel data entry from all individuals, a smooth sequence for the meeting, forced focus upon the issues surfaced, fast issue organization, and multiple methods for establishing priorities.

Multi User Domains

Multi User Domains enable the simulation of four key human activities (Robinett, 1994): look around; move through the world and see it from different viewpoints; perform actions that can change the world; and talk with other people. They also follow principals that include (Anders, 1999) avatar representation, avatar perspective, and spatial simulation. These principles can be used to develop ecological games for environmental education. Multi-user simulations in virtual environments tend to be implemented as distributed interactive simulations (Robinett, 1994; Hoxie et al., 1998).

Tangible Augmented Reality Interfaces

Tangible augmented reality interfaces are those in which each virtual object is registered to a physical object and the user interacts with virtual objects by manipulating the corresponding tangible objects. In this way the display space and communication space can become one (Billinghurst *et al.,* 2001). Although tangible augmented reality interfaces provide a natural environment for viewing spatial data it is often challenging to interact with and change the virtual content. Examples are: Studierstube (Figure 4.2), a system in which co-located users can view and manipulate virtual models while seeing each other in the real world, facilitating very natural face to face communication (Schmalsteig *et al.,* 1996; Fuhrmann *et al.,* 1998); Shared Space, a collaborative game designed to be used by complete novices; AR PRISM, an interface for geospatial visualization; and Tiles, a virtual prototyping application (Billinghurst *et al.,* 2001).

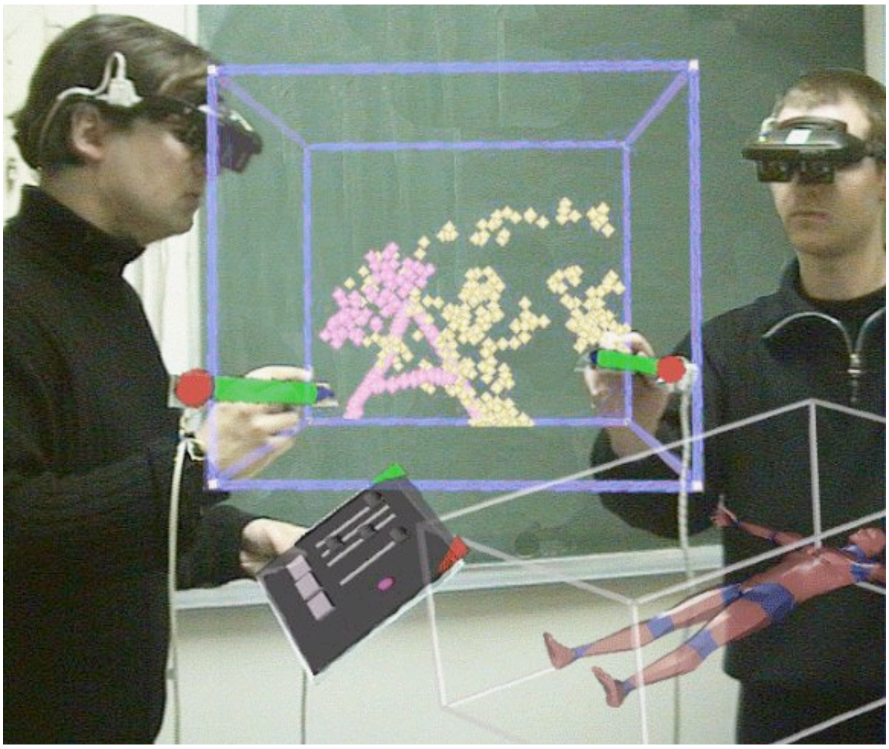


Figure 4.2 Studierstube.

Source: www.studierstube.icg.tu-graz.ac.at.

4.2.1 Asynchronous Collaborative Visualization

By partitioning work across both time and space, asynchronous collaboration offers greater scalability for group-oriented analysis. There is evidence that, due in part to a greater division of labour, asynchronous decision making can result in higher-quality outcomes than face-to-face collaboration: broader discussions, more complete reports, and longer solutions (Benbunan-Fich *et al.*, 2003). The most interesting tools from the standpoint of GIS asynchronous visualization are interactive applications enabling annotation and bookmarking, electronic mail, collaborative database systems and workflow systems (Saunders, 1997).

Annotation and Bookmarking

For users to collaborate, they must be able to share what they are seeing in order to establish a common ground for discussion (Clark and Brennan, 1991). Application bookmarks are Uniform Resource Locators (URLs) or URL-like objects that point back into a particular state of the application. Bookmarks are used in discussion forums surrounding a visualization, in which there are unidirectional links from the discussion to the visualization. Google Earth (Figure 2.6) provides discussion forums with messages that include bookmarks into the visualized globe.

If in these systems there's no way to discover related comments while navigating the visualization, on the other hand, visual annotation systems, such as the regional annotations in Wikimapia (Figure 4.3) or the anchored conversations of Churchil *et al.*, (2000), enable embedded discussions that place conversational markers directly within a visualization or document. The discussion of a specific item may be accessed through a linked annotation shown within the visualization itself. Research efforts into these systems are the Collaborative Annotations on Visualizations (Ellis and Groth, 2004), which enable users to attach graphical, audio, and text annotations to frames of a visualization movie. Online mapping systems, such as Google Maps, also provide support for extended discussions or

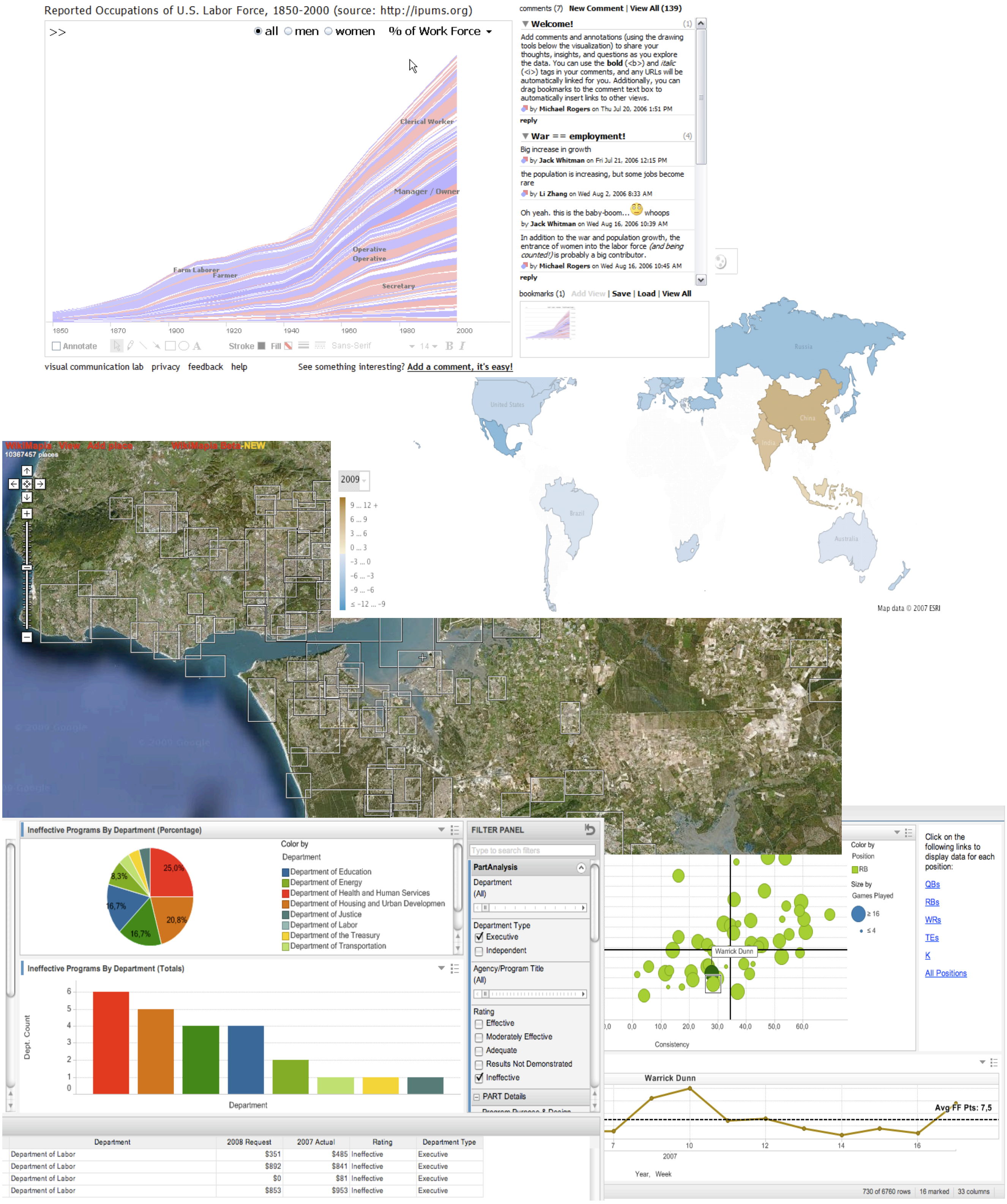


Figure 4.3 (Downwards) Sense.us, ManyEyes, Wikimapia, Spotfire.

Sources: http://sense.us; http://manyeyes.alphaworks.ibm.com/manyeyes; http://wikimapia.org; http://spotfire.tibco.com.

social navigation bookmarks that can be shared among users. The website Swivel enables collaborative sharing of univariate data sets and supports textual comments around static line charts of selected data. The visualization company Spotfire provides DecisionSite Posters (Figure 4.3), a web-based system that allows a user to post an interactive visualization view that other users can explore and comment on. Other two recent efforts to support and develop asynchronous collaborative visualization are the websites Sense.us and ManyEyes (Figure 4.3), both by the IBM Research Group. Sense.us is a website that aims at group exploration of demographic data. The site provides a suite of interactive visualizations and facilitates collaboration through bookmarking of views, saved trails of these bookmarks, doubly-linked discussion, graphical annotation, and social navigation through comment listings and user profiles (Heer *et al.*, 2007). Many Eyes is a participatory website, such as Flickr and YouTube, in which the central activities on the site are to upload data, construct visualizations, and leave comments on either data sets or visualizations. All visualizations and data sets on Many Eyes have an attached discussion forum where users can share textual comments and links to other WebPages (Viégas *et al.*, 2007).

Electronic Mail

Electronic Mail (Email) systems operate over networks, exchanging digital messages that include content, author address and recipient addresses. These systems are based on store-and-forward models in which email computer server systems accept, forward, deliver and store messages on behalf of users who only need to connect to the email infrastructure with network-enabled devices for the duration of the message submission to, or retrieval from, their designated server. Once an email user connects to the Internet he may join LISTSERV groups. These groups are forums for discussing issues of similar interest through the e-mail system (Saunders, 1997). Collaboration through shared email boxes is an example of how tools developed primarily with individual users in mind are re-purposed to support shared work. Muller and Gruen (2005) have conducted studies on the shared use of email boxes in schools, museums and support centres, specifically between executives and assistants.

Collaborative Database Systems

Collaborative databases include tight integration with e-mail, replication of data worldwide, control of access to data through distributed database managers, built-in discussion threads, group database templates, a common collective user interface, and also meta information about group activity. The contents of the database vary widely dependent upon the application. Lotus Notes has dominated this arena.

Workflow

Workflow technology is a provision for computer based aids to enhance the flow of the essential business information and process in an organization. It consists of examining data and information flows and programming a cooperating database and e-mail system to streamline those flows. The first phase implies to document activity such as the current data collection and routing processes, volumes, how individuals act upon what data, decision points, which decisions are made, and how the decisions affect the flow. Tools for performing this type of analysis are based upon discrete event or continuous simulation. Specific vendors include ProcessModel, SIMPROCESS, PowerSim, and iThink. After this first examination, the system is cooperatively re-designed and programmed to reflect a streamlined flow. The routing via e-mail automatically updates, validates and verifies the data as it is passed through appropriate channels (Saunders, 1997). Some of the major tools for these tasks include Action Workflow, and JetForm's JetForm.

4.3 Design Considerations for Collaborative Visualization

Collaboration environments must be structured through shared artefacts and effective communication mechanisms. Based upon research in analytics, social psychology, sociology, organizational studies, and CSCW, Heer and Agrawala (2008) identify a set of design considerations for collaborative visualization systems development: division and allocation of work, common ground and awareness, reference and deixis, incentives and engagement, identity, trust, and reputation, group dynamics, and consensus and decision making.

4.3.1 Division and Allocation of Work

Successful collaboration requires effective division of labour among peers. Segmentation of effort into proper units of work and allocation of tasks to match individuals' skills and disposition are primary concerns on how to divide work among multiple participants and aggregate the results. Benkler (2002) describes the role of modularity, granularity, and cost of integration, as important features to take into account when distributing and allocating work in collaborative environments. Modularity refers to the segmentation of work into atomic units, dividing work into independent tasks. Granularity of a module is a measure of the cost or effort involved in performing the task, being a function of the incentives for performing the work. Cost of integration is linked to the effort required to synthesize the contributions of each individual module. Automatic integration through technological means, integration as additional collaborative task, and social pressure and moderation, are some of the strategies to handle integration and manage its costs.

To determine the modules of work and their granularity, structural models of visualization design and sensemaking processes are used (Card *et al.,* 1999; Heer and Agrawala, 2006; Russell *et al.,* 1993). Once the modules have been identified, the collaboration can be designed in order to reduce the structural cost of the tasks.

4.3.2 Common Ground and Awareness

Clark and Brennan (1991) define common ground as the shared understanding between conversational participants enabling communication. Both positive evidence of convergence of understanding and negative evidence of misunderstanding are used to establish a common ground. Collaborative visualization systems must provide the same visual environment to different participants in order to ground each ones' actions and comments. For this, one can use visualization bookmarks for unidirectional and independent discussion, linking text to the visualization, or embedded discussion, placing conversational markers directly within the visualization, pointing from the visualization to text. A development from these two approaches is the doubly-linked one, in which comments are linked to specific views while also enabling all such discussions to be retrieved in situ as visualization views are visited (Heer *et al.*, 2007).

Awareness of others' activities is also an important grounding feature, because it allows participants to know what has been done, including the timing and content of the past actions, and what else needs to be done (Carroll *et al.*, 2005; Dourish and Belotti, 1992). The design of collaborative systems must include history and notification mechanisms that allow following actions performed on a given artefact or by specific individuals or groups (Brush *et al.*, 2002).

4.3.3 Reference and Deixis

Reference to objects, groups, or regions visible to participants, are used in collaborative visual media environments. Clark (2003) surveys various forms of spatial indexical references, grouping them into pointing and placing. Pointing behaviours use some form of vectorial reference to direct attention to an object, group, or region of interest, such as pointing a finger or directing one's gaze. Hill *et al.* (1992) discuss that successfully supporting deictic pointing gestures is key to visualization applications, arguing for techniques that realize complex pointing intentions by engaging pre-attentive vision in the service of cognitive tasks. Placing behaviours involve moving an object to a region of space that has a shared, conventional meaning. In addition to directing attention, indexical reference allows patterns of speech and text to change. Participants can use deictic terms like *that* and *there* to invoke indexical referents, simplifying the production of utterances along the principle of the least collaborative effort (Heer and Agrawala, 2008). Clark *et al.* (1983) discuss the ambiguity of reference, demonstrating how interaction techniques for pointing facilitate unambiguous references. Striving for machine-readable forms of pointing or annotation, supporting a navigable index of references, designers allow users to search for commentaries or visualizations that refer a particular data item.

4.3.4 Incentives and Engagement

Incentives increase the quantity and quality of contributions and provide additional motivation in already well established incentive systems. Benkler (2002) divides incentives for collaborative work in three categories: monetary, hedonic and social-psychological. Monetary incentives are material compensations such as salary or cash reward. Hedonic incentives have to do with well-being and inner engagement in the work. Visualization users have an affinity for data which they find personally relevant (Viégas and Wattenberg, 2006; Heer, 2006; Wattenberg and Kriss, 2006). Social-psychological incentives refer to increased status or social capital. Ling *et al.* (2005) discusses how users contribute more if reminded of the uniqueness of their contribution. Positive social feedback on a contribution and the visibility of cooperative behaviour across the community increases contributions (Cheshire, 2006). Heer (2006) discusses how playful activity contributes to the engagement, drawing on theory of games (Caillois, 1961) to analyze the competitive, visceral, and teamwork aspects of play. Scoring mechanisms and games create competitive social-psychological incentives.

4.3.5 Identity, Trust and Reputation

Design considerations for social sensemaking in collaborative environments accrue around issues of identity, reputation and trust. In collaborative environments, a hypothesis suggested by someone more trusted or reputable has a higher probability of being accepted

(Mohammed, 2001), and even an e-mail address can be a cue that leads to a number of inferences about identity and status (Donath, 1998). When designing collaborative visualization systems it is important to take into account if collaborators are already familiar to each other or not. Mechanisms for self-presentation and reputation formation may be needed to be included in the system design through identity markers, such as screen names, demographic profiles, social networks, and group memberships. Design of collaborative systems also as to take into consideration what pieces of information most affect reputation formation. In a visual analysis environment, collaborators might rate each other's contributions according to their interestingness or accuracy. This may help surface contributions with higher relevance, provide a reputation metric for contributors, and provide a social-psychological incentive for high quality contributions (Heer and Agrawala, 2008).

4.3.6 Group Dynamics

Group management mechanisms provide notification and awareness features at the group level. Large groups constitute large labour pools, but can incur social and organizational costs. Beyond certain sizes, additional participants provide decreasing benefits in productivity, suggesting an optimal group size dependent on the nature of the work (Pirolli, 2006). Increased group diversity leads to greater coverage of information and improved decision making. Diversity includes the distribution of domain-specific knowledge, geographical location, culture, and gender. However, diversity can also lead to increased discord and longer decision times (Cummings, 2004; Schultz-Hart et al., 2000).

4.3.7 Consensus and Decision Making

Agreement about the data to collect, its organization and interpretation, and decision making based upon the data, arises in many phases of the sensemaking cycle through discussion or aggregation of individual decisions. Scheff (1967) notes that consensus requires participants to believe that their beliefs are the same and realize that others understand one's position.

Collaborative systems' design must include communication mechanisms, such as collaborative tagging (Golder and Huberman, 2006), that allow participants' assumptions, category labels, and content domains to be labelled and addressed in order to identify the points of dissent, creating focal points for further discussion and negotiation (Mohammed, 2001). Collaborative visualization environments can also provide messaging backchannels for gauging mutual understanding. An important design consideration regarding group consensus has to do with the distribution of information across group members. Both Stasser and Titus (1985), and Gigone and Hastie (1993) discuss how unsuccessful information pooling affects decision-making in the direction of the initial information distribution. Better collective information foraging and exchange, making use of reports and presentations, will inform group decision-making by changing the information distribution.

4.4 Models for Collaborative Geovisualization

The following reference models are examples of how the Haber and McNabb model (Figure 2.2) for visualization in dataflow environments, can be extended for collaborative visualization as proposed by Brodlie (2005).

4.4.1 Single and Shared

In this model there is a single application and its user interface is replicated at different locations, allowing other users to view it on their display (Figure 4.4). Each collaborator is fully aware of what the others are seeing. In this approach the input can be controlled only by one user at a time, implying that, either it is always the same user, either the ability to enter input is made available to all collaborators. The latter possibility requires a token, so that only the person holding it can make the input, preventing confusion and broadening the applicability of the approach. Examples of software that support the distribution of a desktop user interface amongst a group of collaborators are Microsoft NetMeeting (Microsoft Corporation, 2003) and Virtual Network Computing (RealVNC Ltd, 2003).

4.4.2 Single and Replicated

This approach is similar to the previous one, but slightly more flexible. The application is executed at each location and the parameter settings are shared (Figure 4.5). Although the underlying processes are identical on each host machine, the user interface can be presented differently. With different processing speeds of the host machines the module can be executed on the most powerful processor or in parallel across a set of processors, and only the interface executes on every machine. Systems that use this approach in their design

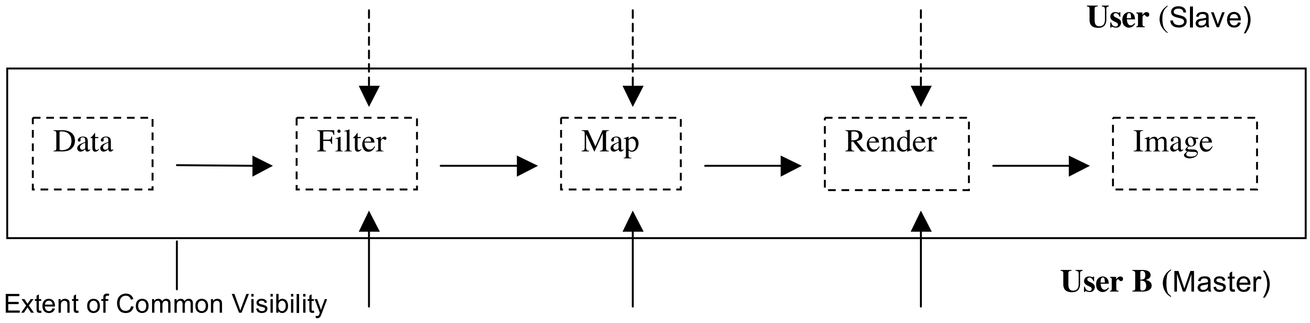


Figure 4.4 Single Application.
Source: Adapted from Brodlie (2005).

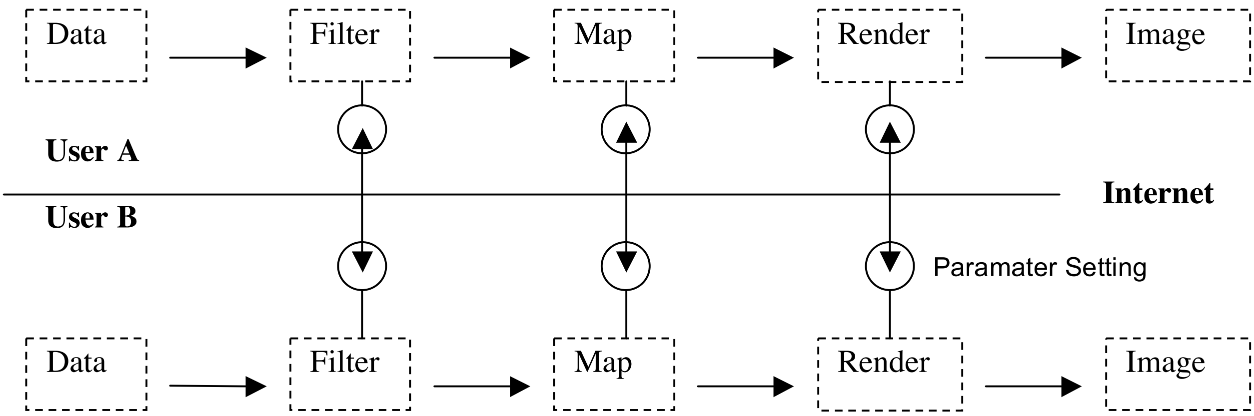
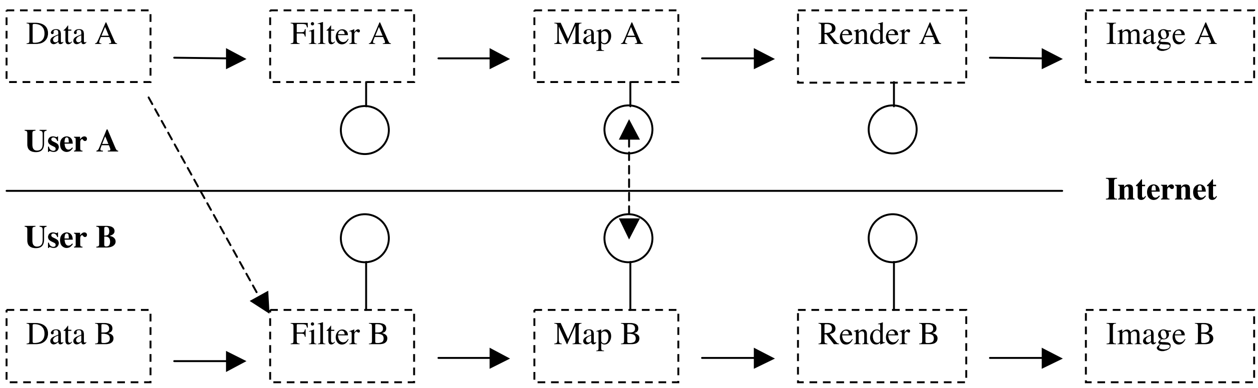


Figure 4.5 Single, Replicated Application.
Source: Adapted from Brodlie (2005).

are SPIDER (Lovegrove, 2003) and COVISE (Wierse and Lang, 2003).

4.4.3 Multiple and Distributed

This is the most flexible approach, since collaborators work both independently, and as a team. Each location runs an individual, independent application, and exchanging of data and parameters between collaborators is done however they wish. Figure 4.6 shows how users A and B share parameter settings on the map process, and how user A sends the data to user B so that user B can use it. Despite of its flexibility, this approach disables any view of the entire distributed system, being difficult to gain a shared sense of what each person is doing. Examples of this model are COVISA (Wood *et al.*, 1997), NAG (NAG Ltd., 2003) and AVS (Duce *et al.*, 1998; Texas Advanced Computing Center, 2003).



Collaboration is Programmed by Sharing Data and Parameters.
Users A and B Execute Independent Applications.

Figure 4.6 Independent Applications, Interlinked as a Single, Distributed Application.
Source: Adapted from Brodlie (2005).

5

Conclusions

5.1 Final Considerations

Ubiquity for Geographical Information Systems has, at present, its core issues in the realms of interoperability and wireless technologies. Though there are a significant number of wireless technologies with the capability to service a large number of mobile GIS users, there is insufficient infrastructure to support these technologies, and there is not sufficient commercial availability of wireless devices to take advantage of these services over the existing communication networks. GIS response time will remain inadequate while using WAP and HTML protocols as Internet mobile standards. Scalable graphics, fast download time, and high performance zooming and panning can be achieved using the Scalable Vector Graphics (SVG) standard, which suggests a hybrid standard of WAP and SVG as logical for ubiquitous GIS applications. Security must also be taken in consideration when designing distributed GIS. In order for users to obtain consistent access to the system, firewalls should recognise mobile devices in ways that do not require registered IP addresses and do not assume devices as foreign and unwelcome visitors.

The ability to handle large volumes of data is an important issue in the current development of ubiquitous GIS. New techniques are needed to tackle large quantities of information, including data cleansing procedures or dealing with missing and uncertain values. The distribution of processing requirements amongst a number of servers needs to include mobile devices as a possible source of computing resources. Large volumes of information are more efficiently managed with a mobile architecture that can decide, based on knowledge of processing requirements and processor availability, if a process should be implemented on the client or on the server. It is also important to develop a theory for georepresentation methods in order to cope with very large data sets of high dimensionality, containing complex semantic relationships, that vary in certainty, and that depict processes over time. In order to handle large geospatial databases it is also necessary to develop visual approaches to geospatial datamining by bringing together disparate technologies, in order to integrate visual and computational tools that enable human and machine to collaborate in the process of knowledge construction.

GIS must also effectively support more diverse users. It is becoming important for services to reach and empower users regardless of their background, technical disadvantages or personal disabilities. Improvements are needed to deal with the variety of technology used and any specific gaps in a user's knowledge. One step is to improve the general usability of the interface. Interfaces need to address annotation, history keeping, collaboration with peers, and the dissemination of results and procedures used. Faster rendering algorithms, sophisticated aggregation techniques to deal with large datasets, and novel labelling techniques are also needed. Multi-layered design, Integrated Initial Guidance (IIG), and video demonstrations of the interface, are some possible solutions to enable users to get started with an application and improve universal usability. Furthermore, there are a number of issues that should be taken into account regarding interface usability: the implications of the natural forms of representation and interaction; understanding metaphors and knowledge schemata use in the context of geovisualization; the differences between individual and group uses of displays; and support of different user perspectives. In geovisualization new interface paradigms are needed to support interaction and individual differences with advanced forms of representation and analysis. There is the need to develop an understanding of the cognitive and usability aspects of controls and metaphor use and how these aspects change in multi-sensory or collaborative environments. There is a need to develop a better understanding of how ordinary users interact with geospatial displays. Finally, a typology of geospatial interface tasks is needed to structure both design of tools and formal testing.

In geospatial collaborative visualization participants embody different domains of knowledge and are likely to expect and require different ontologies through which to interpret the task and the information available. To address this reality, it is necessary to develop visualization methods and tools that facilitate map-mediated dialogue by helping to create shared semantic frameworks among participants. It is also necessary to deal with negative impacts of map-based implementations that impede dialogue in geocollaboration, such as the lack of naturalness in interface styles and controls, and constraints on vision imposed by goggles used to support 3D stereo viewing. In order to understand the interactions among users, tasks, and technologies that lead to productive group work, it is required to conduct both user task analyses and empirical studies that focus on specific user-task-tool combinations. This will help to determine how groups work together using current geospatial technologies and to take into consideration the kinds of functionalities and features that might be included in collaborative tools to enhance that work. There is also the need to develop a theoretical understanding of the cognitive and social aspects of both local and remote collaboration mediated through display objects in a geospatial context. For better collaborative visualization there is the need to create mechanisms to aid the creation and distribution of presentations, in order to parallelize work, facilitate mutual understanding, and reduce the costs of collaborative tasks. Support to build and export presentations semi-automatically will allow users to construct and share trails of related views and to create tours spanning multiple visualizations.

5.2 Future Work

Openness, interoperability and distribution in collaborative geovisualization, are major directions to which future work must be dedicated in order to develop standards and generate tools and techniques that are fully operational and ready for effective application. Further research on collaborative geovisualization must address different contexts, such as, decision support, design, knowledge construction, and education; their respective collaboration tasks; the required common ground and perspective for each field; the different location and time dynamics of work; its group connections and typology; and the adequate representation of information, participants and their behaviours. More specifically, it is also important to understand how different discussion and representations models affect participation, grounding and the cost of integration; how can object recognition be levelled between human and machine collaborators; how can pointing and graphical annotation handle dynamic visualizations and changing data sets; how can automated techniques be used to allocate effort; and how can the results of collaborative visual analysis be more effectively exported, shared and embedded in external media.

Appendix 1

References

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